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STREET LIGHTING PRACTICE

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BY

WARD HARRISON

*Director of Engineering, Edison Lamp Works, National Lamp
Works of General Electric Company, Nela Park; Past
President, Illuminating Engineering Society*

O. F. HAAS

*Assistant General Manager, Atlantic Division, National Lamp
Works of General Electric Company*

AND

KIRK M. REID

*Engineering Department, Edison Lamp Works, National
Lamp Works of General Electric Company*

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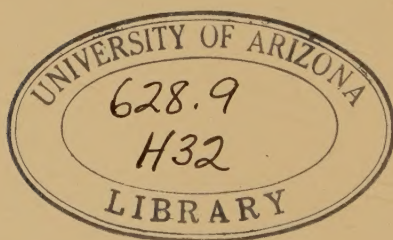
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PREFACE

During the two past decades the authors have frequently been consulted on the general problems of street illumination. With the growing interest in street lighting, on the part of the industry and of the public, inquiries have increased markedly in number. It was with the thought of making available in one place such information as the authors have, that the writing of this book was undertaken.

The subject matter here covered ranges from problems of a purely engineering character, such as the choice of equipment based on light distribution, the proper location of lighting units, series versus multiple circuits, the evaluation of glare, and installation and operating costs, to problems of contractual relations, of methods of financing, of maintenance provisions, and even of the history of street illumination.

Much effort has been devoted to the selection and preparation of the charts, illustrations, and distribution curves, numbering more than two hundred in all, and particular care has been taken in every case to render them authoritative and complete.

The authors are particularly indebted to Mr. G. H. Stickney for furnishing the chapter on "Contracts and Specifications," which adds much to the usefulness of the book. They are likewise indebted to Mr. G. R. Baumgartner for the many photometric tests which he has conducted in order to provide authoritative and comparable data covering a wide range of street lighting equipments.

THE AUTHORS.

CLEVELAND, OHIO,
January, 1930.

CONTENTS

Preface	PAGE V
CHAPTER I	
Historical	1
CHAPTER II	
A View of the Problem.	10
CHAPTER III	
The Value of Street Lighting	14
CHAPTER IV	
Illuminants—Gas Lamps.	28
CHAPTER V	
Illuminants—Arc Lamps.	30
CHAPTER VI	
Illuminants—Incandescent Lamps.	41
CHAPTER VII	
Reflecting, Refracting, and Diffusing Media.	55
CHAPTER VIII	
Series Systems and Their Control.	74
CHAPTER IX	
Multiple Systems and Their Control.	95
CHAPTER X	
Factors Affecting Visibility on the Street.	106

CHAPTER XI

	PAGE
Zoning of Street Lighting.	121

CHAPTER XII

Lighting Plans for Business Districts.	128
--	-----

CHAPTER XIII

Types of Ornamental Street-lighting Posts	135
---	-----

CHAPTER XIV

Lighting Plans for Thoroughfares	145
--	-----

CHAPTER XV

Lighting Plans for Residence Streets.	150
---	-----

CHAPTER XVI

Highway Lighting.	155
---------------------------	-----

CHAPTER XVII

Practical Rules for the Location of Lighting Units.	161
---	-----

CHAPTER XVIII

Cable—Overhead and Underground.	164
---	-----

CHAPTER XIX

Systematized Maintenance.	168
-----------------------------------	-----

CHAPTER XX

Operating Costs.	178
--------------------------	-----

CHAPTER XXI

Methods of Financing	183
--------------------------------	-----

CHAPTER XXII

Contracts and Specifications	187
--	-----

APPENDIX A

Explanation and Definition of Terms	196
---	-----

CONTENTS

ix

APPENDIX B

	PAGE
Illumination Measurements and Calculations.	205

APPENDIX C

Principles of Street Lighting	225
---	-----

APPENDIX D

Ohio Highway Lighting Bill	235
--------------------------------------	-----

APPENDIX E

Representative Candlepower Distribution Curves	241
Index	265

STREET LIGHTING PRACTICE

CHAPTER I

HISTORICAL

“The light of the sun is succeeded by other lights, which are far superior to the lamps lighted by Egyptians on the festival of Minerva of Sais. The night with us differs from the day only in the appearance of the light; with regard to labor and employment everything goes on well.”

So wrote Libanius of the street lights in the city of Antioch in the early years of the fourth century. And while his enthusiastic statement is fraught with poetic license, it verifies that considerable progress had already been made beyond the time when the burning fagot was the only source of artificial illumination.

Authentic references to street lighting in the next thousand years are meager, but the indications are that iron baskets of burning wood, primitive oil lamps, and candles were used to some extent. In 1417, the Mayor of London made what was probably the first attempt at comprehensive street lighting when he ordained that “lanthorns with lights to bee hanged out on the winter evenings betwixt Hallowtide and Candlemasse.” Two centuries later, in Paris, orders were issued to keep lights burning in the windows of houses that fronted on the street as a means of reducing street crimes.

Historical novels tell of the watchman in his rounds enforcing official mandates to hang out lanthorns at an appointed time, chanting:

A light here, maids, hang out your lights
And see your horns be clear and bright,
That so your candle clear may shine
Continuing from six till nine;
That honest men that walk along
May see to pass safe without wrong.

These were the days of the link-boy who figures so romantically in medieval history, lighting venturesome parties and those whose business made it imperative that they be out after darkness had fallen.

In 1736, the Lord Mayor and Common Council petitioned Parliament to erect lamps for street lighting. Such an act was passed, and two years later there were 15,000 oil street lamps in London burning on an all-night schedule.



FIG. 1.—The first street lights were probably burning fagots.

In 1763, a new type of equipment utilizing polished-metal reflectors called “reverbere” was developed in Paris. An account of this interesting development is given on page 55, in the chapter on Reflecting, Refracting, and Diffusing Media.

Street lighting with gas was first introduced in London about 1809 with such success that its use spread rapidly. Its introduction probably marked the real beginning of public-service lighting companies, and gave to street lighting its first great impetus. As with other great innovations, however, it had its oppositions and its setbacks. The objections put forward against street lighting may have retarded its progress somewhat, although

today we laugh at these "Arguments against Light," which appeared in the *Cologne Zeitung* in 1816:

1. From the theological standpoint: Artificial illumination is an attempt to interfere with the divine plan of the world, which has preordained darkness during the night time.
2. From the juridical standpoint: Those people who do not want light ought not to be compelled to pay for its use.
3. From the medical standpoint: The emanations of illuminating gas are injurious. Moreover, illuminated streets would induce people to remain later out of doors, leading to an increase in ailments caused by colds.
4. From the moral standpoint: The fear of darkness will vanish and drunkenness and depravity increase.
5. From the viewpoint of the police: The horses will get frightened and the thieves emboldened.
6. From the point of view of national economy: Great sums of money will be exported to foreign countries.
7. From the point of view of the common people: The constant illumination of streets by night will rob festive illuminations of their charm.

Although gas lighting was adopted almost universally for the lighting of the more important city sections early in the nineteenth century, it was generally supplemented in the outlying sections by lanterns burning animal or vegetable oil. Between 1860 and 1870, petroleum oils displaced the oils previously used.

The "Jablochkoff candle," a form of arc light, was first introduced in 1878 in Paris. During this year, London also had in operation a series circuit of about six arc lamps.

In the year 1879, the Public Square of Cleveland was illuminated by Brush with 12 carbon-arc lamps. The age of electricity had come and the world was to see in the next 50 years gigantic progress toward that ultimate goal of street lighting—streets that are as safe by night as by day—more progress than in all the centuries that preceded.

The Brush series system was closely followed by the Thomson-Houston, and within a short time 250,000 open-carbon arcs, in most cases 10 amp., were in operation in this country. The open-carbon arc had, however, a number of serious inherent defects. An unsteady light source, a poor distribution of light, and the necessity of daily trimming were factors which led to the early development of the enclosed-arc lamp. The enclosed-arc lamp,



FIG. 2.—The fagots were followed by stationary iron baskets of burning wood.



FIG. 3.—Later, oil hand lanterns were widely used, especially on festive occasions.
(From H. R. D'Allemagne, "*Histoire du Luminaire.*")

first introduced in 1893, had the advantage of requiring trimming only about once a week, and on account of this it replaced the open arc in many installations, although the efficiency of light production was decidedly lower.

Next came the flame arc in which most of the light was given off by the luminous flame, while the heated electrodes were but minor sources of light. The flame arcs were never highly successful, for although they were efficient in light generation



FIG. 4.—Parisian night watchmen in the sixteenth century carried candle lanterns. (From P. S. Millar, "*Historical Sketch of Street Lighting.*")

they were never wholly satisfactory from the standpoint of operating cost and maintenance of candlepower.

The direct-current magnetite-arc lamp with its positive electrode of copper and negative electrode of magnetite was developed about 1904. Later, improvements were made in the electrode mixture and this lamp in the 6.6-amp. type is still being installed commercially today. Its efficiency of light generation is high, the arc is comparatively steady, and the light is of a pleasing color.

Paralleling the development of the arc lamp, the incandescent lamp was introduced commercially in 1879 when Edison brought

out his first lamp consisting of a carbonized bamboo fiber filament operated in a glass bulb from which the air had been exhausted. So popular was this lamp that during the first year it was on the market 25,000 were made and sold. These lamps operated at an efficiency of approximately 2 lumens per watt. It is of interest that even in 1880 the bases on incandescent lamps were essentially the same as those of today.



FIG. 5.—“A light here, maids, hang out your lights.” (From H. R. D'Allemagne, “*Histoire du Luminaire.*”)

About the year 1891, a lamp having a filament of carbonized cellulose was introduced. This filament was more uniform in diameter and the efficiency was gradually increased to about 3 lumens per watt.

Advances during the next 14 years consisted chiefly of minor changes in mechanical construction. Then, in 1905, came the gem or metallized-filament lamp. The efficiency of this lamp was about 4 lumens per watt. The success of the metallized-filament lamp naturally led to experiment with metal filaments. Osmium-filament lamps were brought out but failed commercially because of a scarcity of the available raw material.

Lamps with tantalum filaments were next put on the market. These lamps operated successfully at about 5 lumens per watt on

direct current but on alternating current the reversals in direction of current had a destructive effect on the filament structure. Also, because of the comparatively low resistance of tantalum,

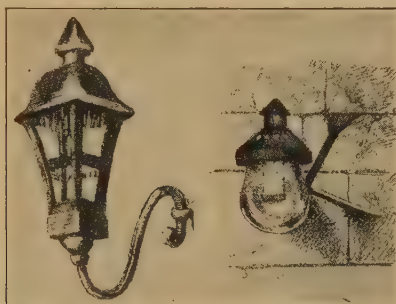


FIG. 6.—Candle lanterns fastened to the building fronts along the principal streets. (From H. R. D'Allemagne, "*Histoire du Luminaire*.")

these filaments had to be about three times as long as the previous filaments used, necessitating a large number of filament loops. Tantalum lamps were not introduced into the street-series field.



FIG. 7.—"Ornamental" street lighting in the Place des Victoires during the seventeenth century. (H. R. D'Allemagne, "*Histoire du Luminaire*.")

Then in 1907 came the tungsten-filament lamp. Tungsten powder with a binding material was squirted through diamond dies and the binder was then removed by special treatment. The result was not altogether satisfactory as the filament was left



FIG. 8.—Eighteenth century "reverbere"—oil lanterns equipped with polished metal reflectors. (H. R. D'Allemagne, "*Histoire du Luminaire.*")



FIG. 9.—Early in the nineteenth century gas was introduced as a street illuminant. (P. S. Millar, "*Historical Sketch of Street Lighting.*")



FIG. 10.—A street lighted with Jablochhoff candles, late in the nineteenth century. (P. S. Millar, "*Historical Sketch of Street Lighting.*")

in a brittle state. Because of their marked advance in efficiency over previous types, however, tungsten lamps were used in great numbers. In 1911, a process was perfected for producing ductile tungsten, and drawn tungsten-filament lamps immediately made their appearance, operating at an efficiency of about 9 lumens per watt. Two years later, certain chemicals were introduced in the bulb to alleviate bulb blackening caused by the deposits of evaporated filament on the bulb. Again the efficiency was increased, and by the end of 1913 the lamps were operating at about 10 lumens per watt.

All through this period of development, incandescent lamps had been used for street lighting to a limited extent. Their lower efficiency was counterbalanced partially by their simplicity of operation and the flexibility of the lamp circuit.

In 1915, came the Mazda C or gas-filled lamp with its coiled tungsten filament operated in the inert gases, nitrogen and argon, at an efficiency as high as 20 lumens per watt. This lamp, with its low first cost, its adaptability to fixture design, and its ease of maintenance, immediately became a powerful contender for dominance in the field of street lighting, against the gas lamps and arc lamps—the recognized pathfinders in the art.

CHAPTER II

A VIEW OF THE PROBLEM

Different types of streets, varieties of equipments available, the ever-present questions of finance—these are some of the complexities brought to mind by the term, “street lighting.” It may be clarifying, therefore, to set down the principal requirements which must be met by every good street-lighting system. Briefly, these requirements are:

1. To provide sufficient illumination to facilitate the movement of vehicles and pedestrians through all the streets of a city without danger of accident or fear of molestation.

2. To supply this illumination with equipment which does not detract from the appearance of the streets either by day or by night.

3. To secure this illumination at an expenditure comparable with the funds that can be had for the purpose.

Where elaborate ornamental equipment and extremely large lamps are employed for the advertising value of the so-called “white-way” system, plenty of money is usually available and attractive appearance is the chief consideration. In these cases the level of illumination, while perhaps not high enough to permit really comfortable use of the street, is almost always above the minimum requirements defined above.

For the majority of streets, only a limited amount of money is available, and it is this fact which in recent years has made adequate street lighting truly a “problem.” The rapid growth of cities and the addition of millions of motor vehicles each year to our already congested thoroughfares have created an imperative need for higher levels of street illumination. At the same time, the demands on a city’s treasury for other needs have also been great and usually more loudly advertised. As a result, the task of the street-lighting engineer ordinarily resolves itself into one of distributing an insufficient amount of light over the streets of the city in such a way as to result in a minimum of deficiency in illuminating effect.

Just how great the stretching process has had to be is better realized from the fact that between 25 and 30 per cent of the total acreage within a city's limits is ordinarily taken up by its streets. In all except the main business centers, the street areas consider-

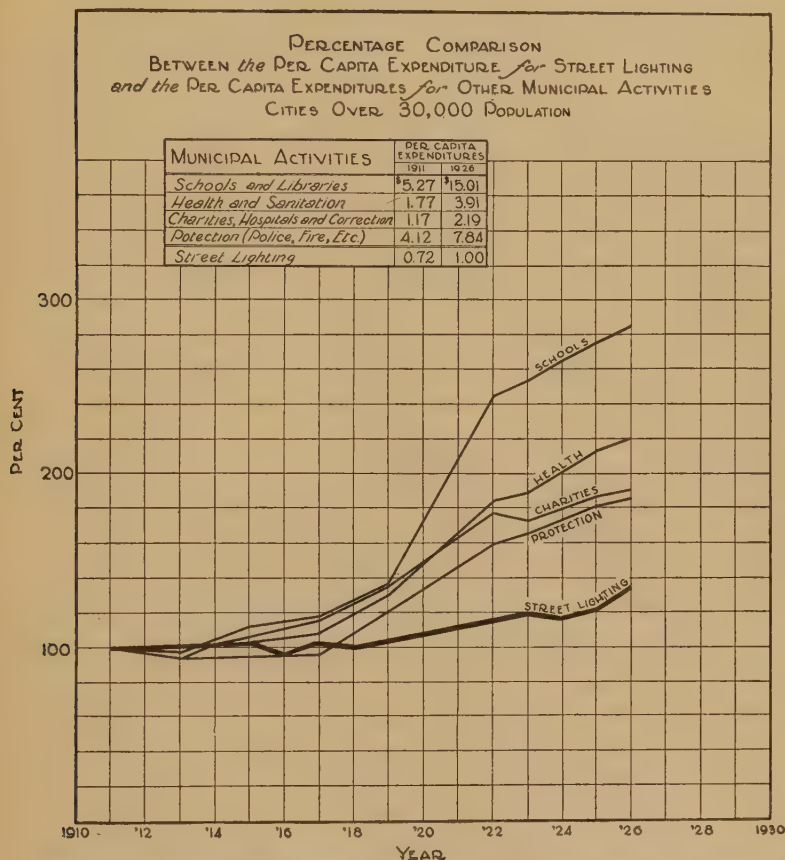


FIG. 11.—Although street lighting lags far behind in comparison with expenditures for other municipal activities, an increasing appreciation of its value is indicated in 1925 and 1926. (Data from U. S. Department of Commerce.)

ably exceed the total floor areas of the adjacent buildings, yet the city's annual appropriation for street lighting is but an insignificant fraction of what its citizens spend every year for interior illumination.

To cite a single example, an office space 50 by 100 ft. is not infrequently supplied with more lamps and a greater wattage

than 2 to 3 miles of the principal thoroughfares of the city in which that office is located. The relative levels of illumination under these circumstances bear the ratio of something like 500 to 1. Such being the case, it is obvious that street lighting has but little in common with interior-lighting practice.

Again, the street-lighting problem is not made easier by a comparison with daylight values. Natural light in rooms having good window exposure ordinarily ranges between 10 and 50 foot-candles, while good artificial lighting in the same rooms is 10 to 15 foot-candles—figures which are at least comparable. In marked

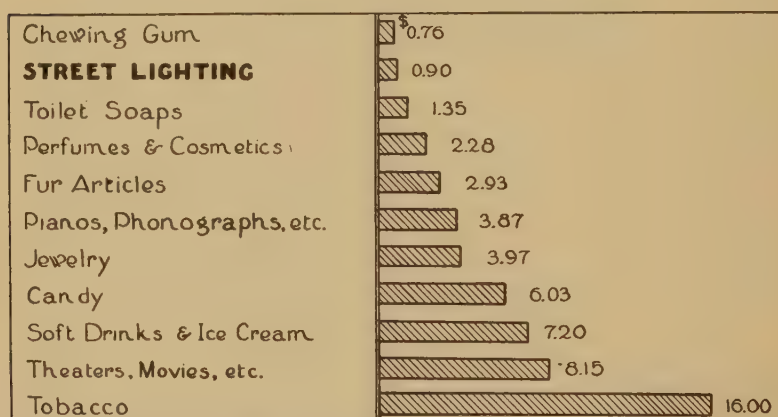


FIG. 12.—The per capita expenditure for luxuries in this country is far in excess of the per capita expenditure for street lighting. Figures for 1924. (Data from U. S. Treasury Department.)

contrast, daylight illumination on the street ranges from 100 to 10,000 foot-candles, while the artificial lighting, except in retail business districts, is usually from $\frac{1}{10}$ to $\frac{1}{100}$ foot-candle.

When dealing with such very meager levels of illumination as these, many of the recognized principles of interior lighting—such as color discrimination and three-dimensional vision—must be laid aside. As far as the motorist is concerned, it is possible to depend only slightly upon direct illumination of the objects on the street, and the revealing power of silhouette, glint, and shadow must be developed to a maximum degree. As discussed in Chap. X, these aids to vision reveal the outlines of objects on the roadway, show whether the direction of travel is toward or away from the observer, and even give a general indication of the rate at

which they are moving. Direct illumination, even where it is meager, is the main reliance of the pedestrian, but to the motorist it is a real factor only in the best business districts where, as has been stated, high intensity or "white-way" lighting is considered as an advertising expenditure to be made either by the city itself or by the local merchants, and the illumination runs up to a foot-candle or even more. Ordinarily, however, this high-intensity system covers but a small fraction of the total mileage of a city.

In the past, the street-lighting engineer has usually addressed himself solely to the problem of utilizing to best advantage the funds placed at his disposal by municipality authorities. Fortunately, during the past two decades, there have been so many improvements in lamps and accessories that, for a given appropriation per mile, street lighting is now substantially better than could be had a few years ago.

It appears that the refinements in lamps and accessories have now progressed to such a point that, unless major discoveries are made leading to substantial improvements in the efficiency of light production, we can expect but little more for a given expenditure than is obtained in the best installations today. In other words, improved street lighting cannot be had in the future without increased appropriations, and it is therefore essential that the engineer analyze the benefits to a city resulting from a given expenditure for street illumination and determine if possible whether added appropriations will in the long run prove an economy. It is recognized by all that the major purposes of street lighting are to reduce the danger of accident and to act as a deterrent to crime—the engineer and the municipality must evaluate street lighting in these terms.

CHAPTER III

THE VALUE OF STREET LIGHTING

Adequate street lighting is a municipal necessity. Its benefits are directly allied with the aims of those who are encouraging civic advancement; its services are real contributions to the safety, comfort, and convenience of the citizens.

The advantages of modern street lighting may be summed up under two main headings, as follows:

The Show Window of the City

Attracts out-of-town shoppers.

Advances civic pride.

Stabilizes and increases real-estate values.

Shows progressiveness of administration.

Promotes other civic improvements.

A Guardian of Safety and Comfort

Reduces traffic accidents.

Lessens crime.

Facilitates traffic.

Assists fire and police departments.

Since the reduction of traffic accidents and decrease in crime are street-lighting benefits on which actual figures can be compiled, these will be discussed first.¹

The Cost of Traffic Accidents.—The seriousness of the accident hazard on streets of American cities becomes evident from even a casual inspection of statistics, which show the losses incurred in this continuous waste of life, time, and property. Statistics compiled by the American Road Builders' Association show 79,420 killed and 2,500,000 injured in traffic accidents in the 3-year period ending Jan. 1, 1929. According to this association, in 1928 there were 27,500 motor casualties and 950,000 injured.

To the ever-increasing density of traffic brought about by the very extensive adoption of automobiles must be charged practically all of the increase in street-traffic accidents. In comparison

¹ See Chap. XVI for a discussion of highway accidents.

with 1906, when there were less than 400 deaths in the United States from automobile accidents, the 27,500 motor casualties in 1928 represent an increase of some 6,700 per cent. Further, the total is mounting steadily.

Figures presented by Dr. F. S. Crum¹ show that at least two-thirds of all traffic accidents have occurred in cities of 10,000 inhabitants or more, and on this basis it would appear that the traffic-accident problem is of greatest immediate importance in these larger communities. It is worthy of note, however, that the increasing amount of intercity touring has brought a heavy highway traffic to villages of even the smallest size, and it is therefore apparent that even in smaller communities public safety demands an increased attention toward means for reducing the street-traffic-accident hazard.

As to an evaluation of the annual personal and property loss from automobile accidents in terms of money, Dr. Crum states that while an accurate computation is not possible, the annual sacrifice is fully \$1,000,000,000. This figure appears reasonable when one considers that the survey of traffic accidents, discussed later in this chapter, indicates that for every fatal accident there are about 40 other accidents of sufficient severity to be reported to the police, and also that personal injuries are sustained in approximately one-half of these cases.

Night-traffic Accidents in London and Cleveland.—The appalling figures on traffic accidents naturally give rise to the question—is poor lighting to blame for part of these accidents? Two typical examples—the experiences of London and of Cleveland—indicate that the answer to this question is a decided affirmative.

In London during the World War, street lamps were either extinguished or carefully screened in order to diminish the danger from air raids. Statistics show a marked increase in night-traffic accidents during this period. In the London Metropolitan Police District, from 1913 to 1915 the recorded non-fatal accidents occurring in the daytime increased 34 per cent, while non-fatal accidents at night increased 63 per cent. Similarly, fatal accidents in the daytime increased but 6 per cent while fatal accidents at night increased 21 per cent. The increase in daytime accidents is largely attributable to the increase in the amount

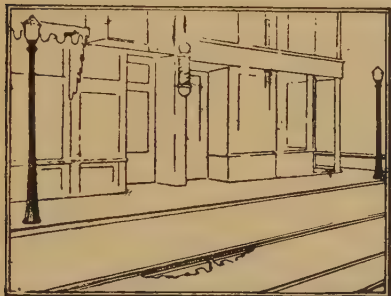
¹ CRUM, DR. F. S., Statistician, Prudential Insurance Company, "Automobile Fatalities."



Fig. 13.—Typical street-traffic accidents at night.

A. Driver runs into obstruction or break in pavement. B. Driver strikes pedestrian stepping into street. C. Driver collides with another vehicle of street car crossing main thoroughfare from side street. D. Driver coming into thoroughfare from side street strikes pedestrian crossing street. E. Driver overruns at dead-end of lane. Fig. 13 shows the proper street lighting to prevent such accidents as these.

of traffic, as has been the experience of municipalities in this country. The *greater* increase in night accidents—that is, the



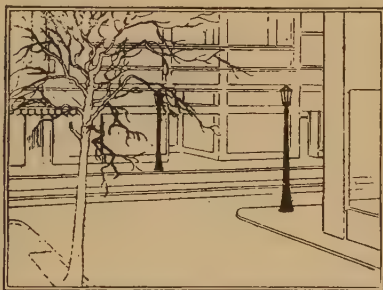
A. A uniform distribution of brightness over the entire street reveals obstructions or dangerous faults in the pavement.



B. The spacing and location of the lamps should be such that a pedestrian stepping into the street or waiting for a car is clearly revealed.



C. Increased illumination warns the driver that he is approaching a main artery of travel.



D. Adequate illumination on a crossing reveals pedestrians to the driver who is coming into a heavy-traffic street.



E. A lamp should be placed at the head of a dead-end street, and on the outside of a turn to illuminate the curb.

FIG. 14.—How good street lighting prevents accidents at night. See Fig. 13.

increase over and above the increase in daytime accidents—is the result of the reduced street illumination

In the city of Cleveland there are several major thoroughfares leading east on which are double-track street-car lines. Of these, Euclid and Woodland avenues from the heart of the city to Fifty-fifth Street have well-designed street-lighting systems consisting of 15,000-lumen (1,500-cp.) and 10,000-lumen (1,000-cp.) Mazda C lamps in ornamental lantern fixtures spaced 90 ft. apart and located opposite each other. In marked contrast, two other thoroughfares, Superior and St. Clair avenues, were very inade-

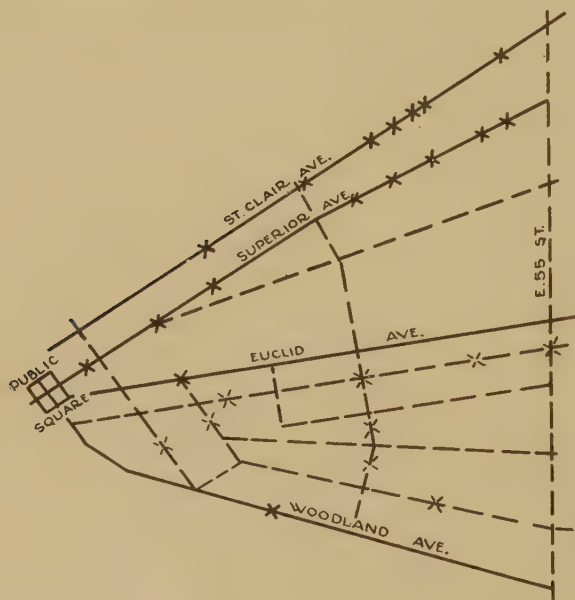


FIG. 15.—On the well-lighted thoroughfares—Euclid and Woodland—only two fatal night-traffic accidents occurred, while on the poorly lighted thoroughfares—St. Clair and Superior—there were fifteen fatal night-traffic accidents.

quately lighted at the time of the survey.¹ Only one 4,000-lumen (400-cp.) lamp for about every 300 ft. of street was provided.

A survey from the Police Department records of automobile-traffic accidents in Cleveland for the year 1923 shows that on Euclid and Woodland avenues only two night fatalities occurred, one on each street, while on Superior Avenue below Fifty-fifth Street there were eight and on St. Clair Avenue, seven, fatal acci-

¹ Data taken for year 1923. These streets have since been adequately lighted.

dents. This is in spite of the fact that during the daytime when, of course, there is no difference in lighting conditions, there were slightly more fatalities on Euclid and Woodland than on Superior and St. Clair. Fig. 15 shows locations of all the fatal night-traffic accidents in the territory covered by the survey.

Survey on Street Lighting and Accidents.—With the purpose of collecting definite data regarding the value which should be attributed to the proper illumination of streets as a factor in the prevention of traffic accidents, a survey of the traffic accidents in a representative group of cities was conducted by E. A. Anderson and the authors.¹ In order to obtain as high a degree of uniformity as possible in the collection of the data, blank forms were prepared providing for a charting of all traffic accidents which had occurred in a given city during the period of 1 year, and for distributing them as to the month and hour of the day at which each occurred, with notations as to whether or not the accident resulted in a fatality.

Through the cooperation of officials and of individuals interested in accident prevention, tabulated reports in a form to be directly applied were obtained from 32 cities with a combined population of over 7,000,000. It was anticipated that there might be considerable variation in conditions existing in individual cities located in different states and it was, therefore, particularly desired to obtain a sufficiently diverse group of cities including a large enough total population to give the presumption of a reasonable degree of accuracy in the results.

The total number of street-traffic accidents reported for 1 year in these 32 cities was 31,475, of which 9,534 or 30.3 per cent occurred during hours of darkness.

The 31,475 traffic accidents are charted in Fig. 16, according to the total number during each month. In certain cities special local influences, such as an excess of traffic at some one season of the year, changed the distribution of accidents considerably, but in most cases the individual reports adhered to the trend shown by the average curve in Fig. 16. At first thought it is somewhat surprising to note that there were a greater number of accidents in the summer months than in winter, as there are a number of influences which tend to increase the hazard in winter, such as stormy, foggy weather, slippery streets, and the impediment of heavy clothing. The traffic, however, is so much greater during

¹ I.E.S. *Trans.*, Vol. XVI, No. 8.

the summer months that in spite of the unfavorable conditions in winter the accident total is less than in the summer months in most cities.

TABLE I.—TRAFFIC-ACCIDENT STATISTICS FOR THIRTY-TWO CITIES DURING A PERIOD OF ONE YEAR
Traffic Accidents Reported

	Total	Night	Total fatal	Night fatal	3 to 5 p.m.		9 to 11 p.m.		6 to 8 p.m.	
					Win-ter ¹	Sum-mer	Win-ter ¹	Sum-mer	Win-ter ¹	Sum-mer
Philadelphia, Pa....	5,231	1,485	190	66	175	251	71	98	164	183
Cleveland, Ohio....	3,549	1,059	174	56	120	120	89	73	154	121
Boston, Mass.....	3,380	1,001	89	38	108	159	57	69	117	131
Pittsburgh, Pa.....	2,950	982	6	2	119	183	57	100	74	109
San Francisco, Cal..	3,014	1,092	76	32	127	106	58	73	110	84
Jersey City, N. J....	672	223	28	13	18	38	8	17	36	32
Rochester, N. Y....	2,570	735	29	9	70	111	34	71	62	119
Portland, Ore.....	1,230	411	31	8	45	43	11	21	38	48
Columbus, Ohio....	193	95	17	9	7	11	6	13	8	7
Hartford, Conn.....	1,389	300	19	6	38	72	12	17	37	57
Grand Rapids, Mich.	255	78	12	4	9	8	1	7	10	12
Youngstown, Ohio..	702	258	33	15	33	31	12	17	28	25
New Bedford, Mass..	699	189	7	3	34	40	6	17	20	31
Lynn, Mass.....	818	278	7	2	35	40	19	20	36	42
Utica, N. Y.....	652	150	9	3	22	43	2	25	16	33
Fort Wayne, Ind....	1,010	241	9	2	42	30	14	13	29	10
Peoria, Ill.....	131	26	7	3	5	11	1	1	5	1
South Bend, Ind....	143	46	6	3	6	6	5	6	7	5
Portland, Me.....	620	177	1	...	16	24	9	16	20	18
Charleston, S. C....	192	52	13	3	6	8	...	7	8	3
Rockford, Ill.....	181	45	11	3	5	15	3	5	3	9
Saginaw, Mich.....	120	48	3	...	...	7	2	3	8	5
Holyoke, Mass.....	287	79	5	2	15	13	5	2	5	15
Gary, Ind.....	281	78	10	4	5	11	3	13	6	12
Malden, Mass.....	187	56	3	...	3	9	...	5	3	13
McKeesport, Pa....	74	30	2	...	1	1	1	3	2	6
New Castle, Pa....	74	31	3	1	3	2	...	5	2	12
Mt. Vernon, N. Y..	264	78	2	1	11	12	3	7	8	12
Evanston, Ill.....	287	81	9	4	7	17	2	7	6	11
Austin, Texas.....	169	75	2	2	9	3	2	2	16	9
Muskogee, Okla....	42	20	2	...	...	3	1	1	2	9
East Cleveland, Ohio	109	35	6	4	1	1	1	6	6	7
Total.....	31,475	9,534	821	298	1,095	1,429	495	740	1,046	1,200

¹ Winter refers to November, December, and January. Summer refers to May, June, and July.

The total accidents reported for the year are charted in Fig. 17 according to the hours of the day during which they occurred. This chart also shows the apparent importance of density of

traffic as a factor in causing accidents. It will be noted that relatively few accidents are reported in the hours from one to seven o'clock in the morning, the period of the day in which

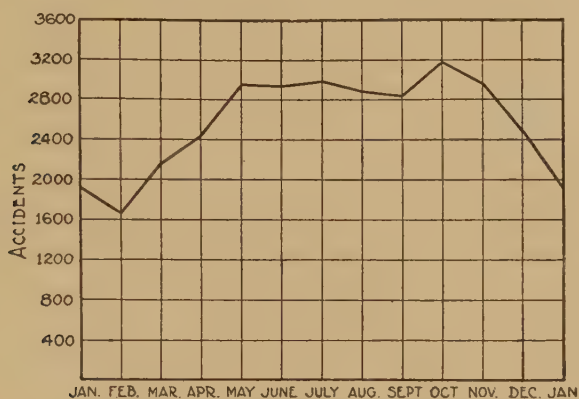


FIG. 16.—Traffic accidents by months.

street traffic is least. On the other hand, the accident rate becomes greatest in the hours from five to six in the afternoon, when in practically every city the streets are congested with the home-going population from offices, stores, and factories.

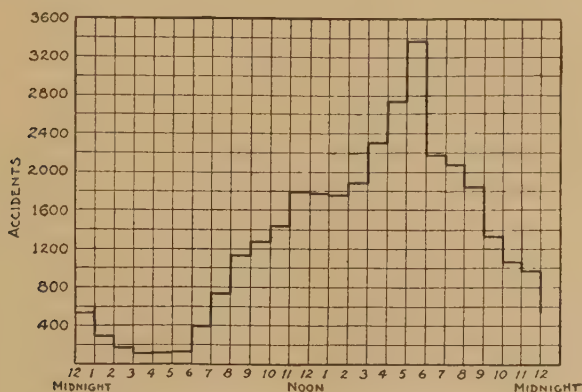


FIG. 17.—Traffic accidents by hours.

Referring to the period from 3 to 5 p.m., which is daylight in both winter and summer, the data in Table I show a total of 1,095 accidents in winter and 1,429 in summer. The winter accidents from 3 to 5 p.m. are, therefore, 76.6 per cent of the

summer total. Considering next the totals for the period of 9 to 11 p.m., which is dark both in winter and summer, it is noted that the accidents are, respectively, 495 and 740. The winter accidents from 9 to 11 p.m. are, therefore, 66.9 per cent of the summer total. If these two percentages of 77.6 and 66.9 are averaged it is indicated that for the group of cities in this survey, traffic conditions are such that, excluding the influences of illumination, the winter accident rate in the afternoon and evening is approximately 71.8 per cent of the summer accident rate.

Considering next the period of 6 to 8 p.m., which in summer is daylight, there is shown a total of 1,200 accidents in the 32 cities during the three months of May, June, and July. Hence, applying the average percentage of winter to summer accidents

NIGHT ACCIDENTS



FIG. 18.—About 17 per cent of city night-traffic accidents are due to inadequate illumination.

(71.8 per cent) determined as above, it would be anticipated that in the three winter months of December, January, and February, there would be 862 (71.8 per cent of 1,200) accidents during the hours of 6 to 8 p.m. The survey, however, shows a total of 1,046 accidents to have actually occurred during these hours in the three winter months, or 184 more than anticipated provided there had been the same effectiveness of illumination in the winter months as in summer. Hence, there is the strongest evidence that 184 accidents, or more than 17 per cent of all those at night, must be attributed to the lack of light during the winter months. Applying this same percentage to the 9,534 accidents which occurred after dark in the 32 cities covered by this survey it appears that 1,678 would have been avoided if adequate illumination had been provided.

Assuming that the same proportion of day and night accidents which was found to exist in this survey holds in all cities, in 1928 there must have been, out of the total of 27,500 killed, about 8,300

deaths from night automobile accidents, and 17 per cent of these, or about 1,400 may be attributed directly to lack of sufficient illumination. In addition to this loss of life, a similar computation shows that the very substantial amount of \$53,000,000 of the billion-dollar annual street-accident loss estimated by Dr. Crum may also be attributed to lack of light. According to census reports, the total expenditure for street lighting in the United States is not in excess of \$50,000,000.

The figure of 17 per cent arrived at as the proportion of night accidents which may be attributed to lack of light, is undoubtedly an extremely conservative figure to use in evaluating the usefulness of illumination in preventing traffic accidents, for, as a matter of fact, the streets of all of the cities covered in the foregoing survey were illuminated at night by artificial lighting of varying degrees of effectiveness. In an individual city where the need for better street lighting is especially evident, the percentage of night accidents chargeable to the lack of light is likely to run as high as 50 per cent. On the other hand, in the case of those districts where fairly high levels of artificial street lighting are provided by "white-way" systems, the percentage of night accidents chargeable to lack of illumination can be said to be fairly low.

While in the present state of the art it is not practical to provide artificial street lighting approaching actual daylight levels, it is entirely feasible to increase the quantity of light to a level from three to five or even ten times as high as that provided by average existing systems, and when this is done, with properly installed equipment, it may be confidently expected that a large measure of the benefit of light in reducing accidents will be obtained.

Influence of Street Lighting on Crime.—So well understood is the preference of the evil doer for darkness that the unusual daring of the man who commits a "daylight" crime is featured in newspaper headlines while the same crime committed at night is noted in a paragraph as a commonplace. The recognized feeling of increased safety amid well-lighted surroundings rests upon a more substantial foundation than simply an inherited dread of the danger of darkness; for the criminal makes his approach without warning when there are dark, shadowy spaces, and his escape is made many times more easy when there are conveniently dark streets and alleys in which detection is difficult.

The effectiveness of street lighting as a deterrent to crime is crystallized in the oft-quoted statement that "a street lamp is as good as a policeman." Unquestionably, good street lighting multiplies the efficiency of the night police force. The most striking illustrations of the importance of lighting in preserving



FIG. 19.—Good street lighting decreases crime.

community safety comes when by accident or otherwise all street lamps are out for a period of time. For example, in Chicago during the war an attempt was made to reduce coal consumption by extinguishing the street lamps. The following newspaper headlines indicated the immediate result:

ELECTRICITY THE SILENT POLICEMAN

CHICAGO DARK; BANDITS BUSY

THIRTY-TWO HOLDUPS AND MANY OTHER CRIMES IN TWO-DAY PERIOD

MAYOR'S MOTOR STOLEN

STREET LIGHTING, TURNED OFF TO SAVE COAL, TURNED ON TO SAVE PEOPLE

Needless to say it was decided that the street lighting was necessary even in the face of a severe fuel shortage.

Cleveland Crime Survey.—While the usefulness of better street lighting in reducing crime has been widely recognized there has

been but little in the way of recorded statistics to measure its influence, except a Cleveland survey by the authors:

Early in the year 1916 a high-intensity ornamental lighting system consisting of lanterns equipped with 10,000-lumen and 15,000-lumen incandescent lamps, spaced approximately 85 ft. apart on each side of the street, was installed in the more important district of the business section of Cleveland. Although the possible effect of the improved illumination in reducing crime was but a secondary consideration at the time of the installation, the widespread increase in the last few years in such crimes as assaults, holdups, and automobile thefts, have focused the attention on methods by which the crime situation could be remedied. It was with the thought of determining just what effect light had on the elimination of crime that a survey was made in Cleveland of

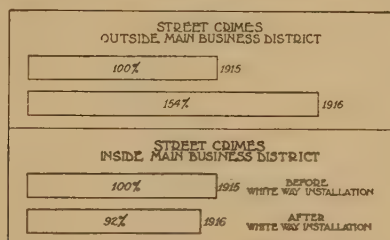


FIG. 20.—In Cleveland, “white-way” lighting reduced crime 8 per cent in the downtown district, during a period in which crime increased 54 per cent in the rest of the city.

the crimes committed both in the city as a whole and in the “white-way” district. More than 1,000 cases of holdup, assault to rob, burglary (buildings entered from the front), automobile theft, pocket picking, etc., were included in this study of the Police Department records.

It was found that 90 per cent of these crimes took place after dark. Furthermore, before the new lighting was installed, 17 out of every 100 of the crimes were committed in the small downtown area designated as the “white-way” district, which embraced less than 1 per cent of the street mileage of the city. Street crimes committed after dark during the months of October, November, and December of the year 1916, after the new lighting was installed, were compared with the corresponding months of the previous year, so that the possible effect of the increased lighting as a deterrent to crime might be determined. It happened that the survey was made at the virtual beginning of a crime wave and that crime was increasing by leaps and bounds in all sections of the country. In Cleveland, in the areas outside of the “white-

way" district, street crimes committed after dark increased 54 per cent over the previous year; crimes in the "white-way" district, however, actually decreased 8 per cent in comparison with the previous year. In other words, after the "white-way" lighting was installed, crimes in the business section of Cleveland were only 60 per cent of what might well have been expected had no change been made in the lighting.

A Contribution to Comfort and Convenience.—While the fundamental or elementary service performed by street lighting is that of accident and crime prevention, it has an equally important part in contributing to the comfort and convenience of the community. A satisfactory street-lighting system not only makes possible the traversing of sidewalks and streets, but effectively reveals minor inequalities in sidewalks and paving surfaces and makes walking both safe and pleasant. Even in less-frequented locations a printed or written address is readable without striking a match. Street signs are well enough lighted to be read easily without the necessity of stopping to decipher them. House numbers are visible at a reasonable distance. Passing friends may be recognized on the streets in any part of the city. In the more congested areas a satisfactory level of illumination makes it possible to read newspapers or other matter while waiting anywhere on the sidewalk. The goal of a street-lighting plan, which is reasonably attainable without an undue expenditure, should be that the normal daylight activities on streets may proceed at night practically without delay or increased difficulty.

Commercial Advantages of Well-planned Lighting.—The experience of dozens of communities has shown that proper street illumination is of advantage in providing favorable conditions for prosperity and progress. There is a distinct gain in business efficiency from the extension of the hours of operation for which the safe and comfortable use of streets at night is a requisite. Further, light exercises a definite attraction for all people. How the illumination of a "white-way" street-lighting system changes a street which previously was practically deserted after sunset into a scene of activity and life throughout the evening hours is a familiar story. In specific instances where only one of two commercial streets was equipped with new lighting, the well-lighted street has gained in the ratio of two to one or even three to one in evening traffic as compared with the poorly lighted street. The effect upon property values of such

a concentration of business is obvious to all familiar with the way trade follows the crowd. Without considering the business interests of the merchants, well-lighted business streets represent a real advantage to that very considerable number of the population engaged in work throughout the day and who, therefore, must do their shopping during the evening hours.

Progressive real-estate promoters have realized the importance of good street lighting in adding to the attractiveness and value of property, and in developing new allotments. Therefore a liberal number of ornamental lamp posts are very commonly installed with underground current supply in place of the meager allowance of lighting equipment which is all the limited municipal appropriations will usually permit in outlying districts. This practice has not only been found to increase the sale value of the property but has sometimes been found to have the additional advantage that it enabled showing the property at night to prospective buyers, some of whom were not able to arrange to come in the daytime.

Modern illuminating engineering has been of great assistance economically in making possible double-shift operation of industrial plants, thereby in many cases reducing the overhead charges on the investment in plant and machinery by as much as one-half. In the development of a level of street lighting such as will enable night traffic to proceed at the same density, speed, convenience, and safety as by day, there is offered a similar important opportunity for community economy. Large as the expenditures are already for improved thoroughfares and highways, engineers estimate that at the present rate of traffic growth duplicate roadways must be built very soon in many districts. This congestion, however, will be greatly relieved and the time when duplicate road construction is required will be postponed for years in many cases, provided a larger proportion of the traffic can be diverted from the crowded day hours. In line with the economy of double-shift use of roads, Arthur Williams, of New York, some time ago presented a paper in which reductions as great as one-half in trucking cost were estimated to be possible by the increased utilization of equipment and terminal facilities and the avoidance of traffic delays by the use of streets during the less-congested night hours.

CHAPTER IV

ILLUMINANTS—GAS LAMPS

As mentioned in Chap. I, the use of gas for street lighting goes back to 1809 when the first installations were made in London. The idea was soon brought to America, and gas street lamps were adopted in Baltimore in 1821. Within 15 years the use of gas had become quite general for outdoor lighting in cities.

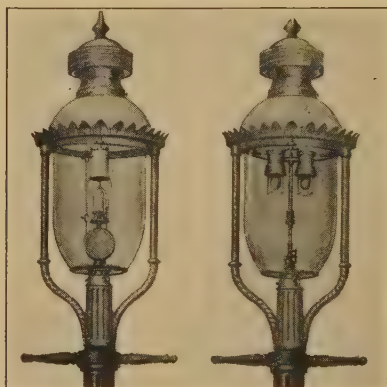


FIG. 21.

FIG. 22.

FIG. 21.—Gas street lamp employing a single upright mantle.

FIG. 22.—Gas street lamp employing two inverted mantles.

(Courtesy of Welsbach Street Lighting Co.)

The outstanding improvement in gas street lighting came with the introduction of the Welsbach mantle about 1885. The 5-ft. open-flame burner previously used produced but 15 to 20 cp., whereas the Welsbach mantle made possible a commercial street lamp rated at 60 cp. for approximately the same or less consumption of gas, *i.e.*, $3\frac{1}{2}$ to 5 cu. ft. per hour.

The most widely used gas street lamp has been the so-called boulevard type with upright mantle burner and chimney (see Fig. 21). The upright mantle has an inherent advantage over the inverted type in that its natural distribution of light is better

suited for street illumination. The somewhat improved efficiency, however, of the inverted burner and particularly its greater durability led to the quite general substitution of two small inverted mantles as in Fig. 22 for the single upright burner. Part of the gain in efficiency of the inverted burner is due to the fact that it has been made to give satisfactory service without the aid of a surrounding chimney; chimneys cause some loss of light even when perfectly clean, and considerably more loss as dust accumulates upon them.

In the days preceding the widespread use of the automobile, lamps of 32 to 80 cp. were considered standard for most street-lighting installations, and the competition between gas-mantle lamps and electric lamps of these sizes was keen. In general, the annual charges made for gas and electric lamps of the same rated candlepower were not far different. The argument usually centered around the allegation that gas lamps in service fell very far below their initial or rated candlepower as shown by laboratory measurements. Many tests were exhibited on both sides tending to prove and to disprove this claim. As a matter of fact, the candlepower of gas-mantle lamps depends almost entirely upon the care in maintaining them, and will be found to range from 20 to 60 cp., depending upon the effectiveness of this maintenance.

With the coming of the automobile, which made essential the use of street lamps of higher candlepower, gas lighting became less and less a factor in new street-lighting installations, although many of these lamps are still in use in older communities.

Abroad, the trend toward higher standards of illumination was accompanied by the introduction of high-pressure gas lamps which utilized one or more inverted mantles of large size, rated at 500 to 1,000 cp. per mantle. The usual gas pressure was approximately 2 lb. per square inch, and the rated efficiency of the lamps was approximately twice that of the ordinary low-pressure burner. Today, in England and in France where the price of electrical energy is materially higher than in this country, high-pressure gas is used to a considerable extent for the lighting of important thoroughfares. In the United States, the comparatively large investment required for special pipe lines and the greater expense of lamp maintenance have proved to be obstacles which high-pressure gas could not overcome.

CHAPTER V

ILLUMINANTS—ARC LAMPS

Arc lamps that have been used in street lighting include the open and enclosed carbon-arc, the open and enclosed flaming-arc and the magnetite-arc lamp.

Open-arc Lamps.—The earliest practical form of arc lamp—now long obsolete—was the so-called open arc, for use on direct current, with carbon electrodes exposed to the atmosphere. In a lamp of this type, most of the light issues from the tip of the



FIG. 23.— Direct-current arc between carbon electrodes.

positive carbon or electrode, known as the “crater” of the arc. This crater has a temperature of from 3000 to 3500° C.—the temperature at which the carbon vaporizes—and it gives from 80 to 85 per cent of the total light emitted by the lamp. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater; it is also incandescent, but not to as great a degree as the positive carbon. Between the electrodes there is a band of violet light, the arc proper, and this is surrounded by a luminous zone of a golden-yellow color. When pure carbon electrodes are used, the arc proper furnishes not more than 5 per cent of the light emitted by the lamp.

In service the carbons are consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative. When this type of lamp was used for street lighting, it was common practice to renew the carbons once a day. The carbons were either molded or forced from a product known as “petroleum coke,” or from similar materials such as lampblack. Plating of the carbons with copper was sometimes resorted to as a means of increasing their conductivity and prolonging their life.

If alternating current is used in an open-arc lamp, the upper and lower carbons become positive and negative alternately,

and there is little opportunity for a crater to be formed. Both carbons give off the same amount of light and are consumed at about the same rate.

A practical open-arc lamp requires not only a pair of carbons for producing the arc, but also a means for supporting the carbons and maintaining them at the proper distance apart, besides a suitable arrangement for carrying the current to them. The carbons must be in contact or brought into contact when the current first flows; immediately afterwards their position must be adjusted at the proper distance to form the arc, and this distance

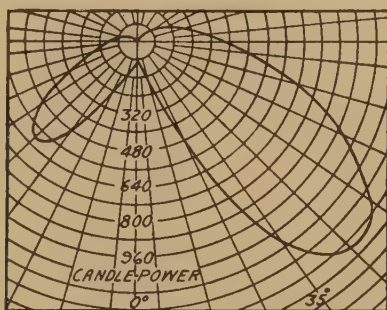


FIG. 24.—Light distribution, in a vertical plane, of a direct-current open-arc lamp.

must be maintained while the carbons are consumed. Again, on series circuits some provision must be made for the continuation of the flow of current after the electrodes are entirely consumed. Although the feeding of carbons may be accomplished by hand, as is the case in some stereopticons using an arc, for street lighting the striking and maintaining of the arc must, of course, be automatic. It is made so by an arrangement of solenoids acting against the force of gravity or against springs.

The principal advantage of the open arc was its high efficiency; with an energy consumption of less than 500 watts, the 9.6-amp. lamp furnished a maximum intensity of about 1,200 cp. Its chief disadvantage from the standpoint of street illumination was its unsuitable light distribution. Fig. 24 shows the light distribution curve of a direct-current open arc, taken in a vertical plane. The maximum candlepower is seen to be downward at an angle of about 45 deg. from the vertical, so there was a very bright ring of light on the street surface near the lamp while that part of the

street farther away was left in comparative darkness. Further, since the lower carbon intercepted practically all of the directly downward light there was a dark spot on the street immediately beneath the lamp.

It will be noted that the curve in Fig. 24 is unsymmetrical. The explanation is that as the electrodes burn away the arc tends to wander from one point to another near the periphery of the carbon, and the candlepower in any given direction depends very much upon the position of the arc at the particular time the reading is taken. The values in Fig. 24 were obtained when the arc happened to be on the right-hand side of the electrodes. The inequality of the distribution of light may be exaggerated by uneven burning of the carbons.

The recognized illumination rating for the open-arc carbon lamp has always been 2,000 cp. The 2,000-cp. value appears in a great many of the old street-lighting contracts and has been the source of much litigation. The origin of the rating probably lay in the fact that the arc lamp gave a great deal more light than any unit previously known, and the photometers in existence at the time of its invention were inadequate for the purpose of measuring such intensities. The decisions of the courts of law passing upon this question have, in general, been to the effect that the 2,000-cp. rating merely described a particular type of lamp and had nothing to do with the actual intensity obtainable from it.

There was also in limited use a so-called "half-arc" lamp embodying the same principles as the open arc. The half arc operated at about 6.6 amp. on 50 volts and gave approximately half the illumination of the standard arc.

Enclosed-arc Lamps.—The enclosed arc—also obsolete—differs from the open arc in that it has an inner or enclosing globe surrounding the arc, and this globe is furnished with a cap which renders it nearly airtight. Under these circumstances, the carbons are not consumed as rapidly as in the open arc because the oxygen is soon exhausted from the inner globe, and the carbons will burn from 80 to 100 hr. without trimming. In general, enclosed arcs for series systems are constructed much the same as the open arcs.

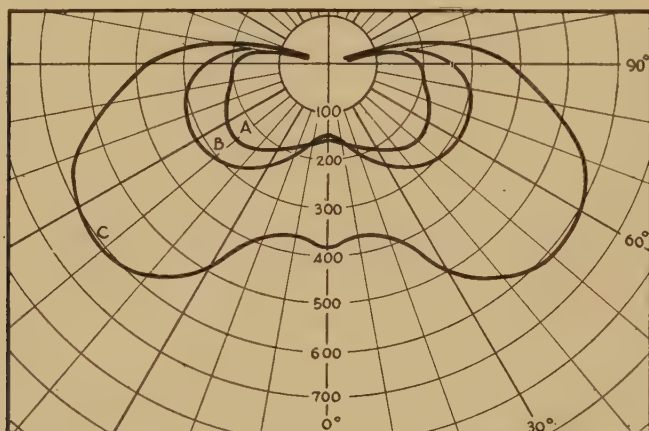
Distribution curves for the three enclosed arcs which were most commonly used in street lighting are shown in Fig. 25, and the data on them are shown in Table II. They required a voltage of from 68 to 75 volts at the arc.

TABLE II.—DATA FOR PENDENT SERIES ENCLOSED CARBON-ARC LAMPS

Unit	Electrode	Equipment	Amperes		Volts		Watts		Total lumens	Lumens per watt	Mean hemi-spherical candlepower	Watts per mean hemi-spherical candlepower	Life of electrode in hours
			Termi- nal	Arc	Termi- nal	Arc	Termi- nal	Arc					
6.6-ampere alternating current	Electra	Light opalescent inner globe, clear outer globe, white porcelain enamel street reflector	6.6	6.25	78	73	450	392	1,810	4.03	215	2.07	90
7.5-ampere alternating current	Electra	Light opal inner globe, clear outer globe, white porcelain enamel street reflector	7.5	7.2	76	72	480	460	2,170	4.53	291	1.65	80
6.6-ampere direct current	Electra	Light opal inner globe, clear outer globe, white porcelain enamel street reflector	6.6	6.5	77.5	75	510	488	3,780	7.42	520	0.98	120

(Data from Ill. Eng. Lab., G. E. Co.)

The direct-current enclosed arc gives a natural downward distribution of light because of the existence of a crater in the upper or positive electrode, although this crater is not so pronounced as in the open arc. The alternating-current enclosed arc, on the other hand, gives approximately the same amount of light in the upper and lower hemispheres, and it was usually the practice to equip it with a flat reflector to redirect a considerable part of the upward light into useful directions.



A—6.6-amp. A. C. arc
B—7.5 amp. A. C. arc
C—6.6-amp. D. C. arc

FIG. 25.—Distribution curves for the three enclosed carbon-arc lamps, with reflectors, as listed in Table II.

The relative effectiveness of the open arc and the enclosed arc for street illumination was not represented fairly by their comparative candlepower values. The greater steadiness of the light from the enclosed lamp was of advantage, and so also was the fact that it gave a relatively greater proportion of its flux at angles near the horizontal, thus tending to avoid dark areas between lamps. The 7.5-amp. alternating-current enclosed arc was generally accepted as fully the equivalent of the so-called 2,000-cp. 9.6-amp. open arc.

Flaming-arc Lamps.—In the open-arc lamp with carbon electrodes, the arc proper gives out but a small percentage of the total amount of light emitted. In order to obtain a lamp having more luminosity in the arc itself, experiments were made employing different electrodes. The result of these experiments was the development of the flaming-arc lamp and the luminous-arc lamp,

both of which have a high candlepower and good efficiency. The flaming-arc lamp uses carbon electrodes, either impregnated with certain salts which add luminosity to the arc, or with cores which contain the required material.

The Bremer flaming-arc lamp, sketched in Fig. 26, was introduced commercially in 1899. In this lamp the electrodes are mounted at an angle with their points projecting into an "economizer" which serves to limit the air supplied to the arc and thus increases the life of the electrodes. An electromagnet is used to blow the arc downward, in order to keep it from creeping up and injuring the economizer, and also for the purpose of spreading the arc out and increasing its surface. The vapor from the arc is condensed on the economizer and this coating acts as a reflector, throwing the light downward. The inclined position of the carbons was suggested by the fact that in the impregnated carbons a slag was formed which gave trouble when the electrodes were mounted one above the other. Also, with the electrodes in this inclined position there is little if any obstruction to the light which passes directly downward from the arc.

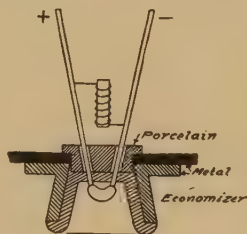


FIG. 26.—Diagram of Bremer flaming-arc lamp.

Bremer's original electrodes contained compounds of calcium, strontium, magnesium, and boracic acid. Later, electrodes of a still greater variety were used, such as impregnated carbon, with a core containing the flaming materials, and metallic wires imbedded in carbon. The life of the electrodes depends upon their length and upon the type of lamp; it was usually about 12 hr. When calcium salts are used as the main impregnating compound in the electrodes, the color of the light from the flaming arc is yellow. A red or pink light is produced by employing more strontium, while a white light is obtained with barium salts. Calcium gives the most efficient service and strontium comes between this and barium.

Commercial lamps using yellow carbons were commonly rated at 3,000 mean lower hemispherical candlepower. This value applied only at the beginning of the trim when the globes were clean and free from deposit. Because of the frequent trimming required, the flaming arc in its original form was considered unsuited to American street-lighting practice, and for this purpose

the enclosed flaming-arc lamp, of inherently longer life, was developed.

In the enclosed flaming-arc lamp shown in Fig. 27, the electrodes are again mounted one above the other, while a close-

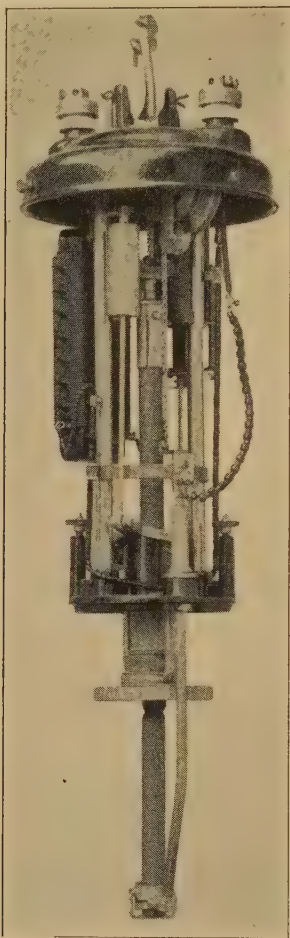


FIG. 27.—Alternating current enclosed flaming-arc lamp, without hood.

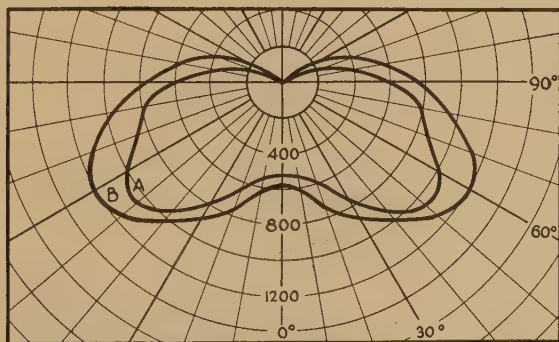
fitting inner globe cuts down the amount of oxygen. The usual design of this type of lamp is for series alternating-current operation with 10 amp. at the electrodes; many of them contain autotransformers so that they may be supplied from 6.6-amp. circuits. Electrical and photometric data for these lamps are shown in Table III and a typical distribution curve is given in Fig.

28. Enclosing the arc increases the life of the electrodes to approximately 100 hr. and, as might be expected, also reduces very materially the candlepower of the lamp. Because of the tendency toward poor candlepower maintenance caused by the deposit of ash on the globes, and because of the relative unsteadiness of their light, enclosed flaming-arc lamps have been superseded for street lighting.

TABLE III.—DATA FOR FLAMING-ARC LAMPS

	Alternating-current series lamp	Direct-current multiple lamp
Terminal volts.....	52	115
Terminal watts.....	425	747.5
Arc volts.....	46	70
Arc watts.....	395	455
Amperes.....	10	6.5
Efficiency, percentage.....	93	61
Power factor, percentage.....	81.6	
Mean hemispherical candlepower.....	1,000	820
Mean spherical candlepower.....	655	500
Mean hemispherical candlepower per watt....	2.35	1.09
Mean spherical candlepower per watt.....	1.54	0.67

(Data from Ill. Eng. Lab., G. E. Co.)



A—6.5-amp. D. C. multiple arc
B—10-amp. A. C. series arc

FIG. 28.—Distribution curves for the flaming-arc lamps listed in Table III.

Magnetite-arc Lamps.—Arc lamps with metallic electrodes were introduced as early as 1903. The type now most commonly

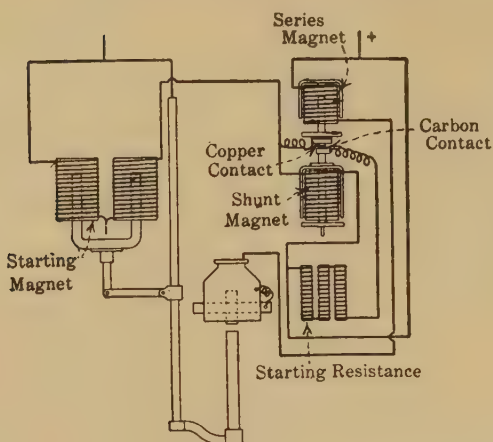


FIG. 29.—Diagram of connections for luminous-arc lamp.

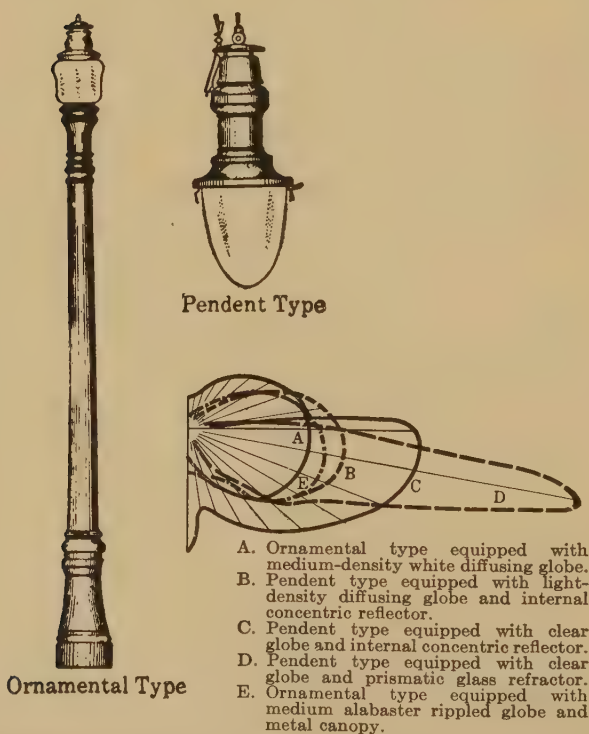


FIG. 30.—Typical distribution curves of luminous-arc lamps with different equipments. Data in Table IV.

employed, known as the luminous arc, used copper as the upper electrode and a magnetite stick as the lower. This lamp has a high efficiency, its light is white in color, and its candlepower maintenance is good. Since the magnetite electrode is not consumed rapidly, the lamp does not require frequent trimming. The electrode is formed by forcing magnetite, to which titanium salts are usually added, into a thin sheet-steel tube; its life is usually from 100 to 350 hr., depending upon the length of the electrode and the amperage of the lamp. Direct current must be used with this lamp, and is usually supplied from mercury-arc rectifier sets, since practically all the magnetite lamps built are of the series type.

TABLE IV.—DATA FOR DIRECT-CURRENT SERIES LUMINOUS-ARC LAMPS

Lamp and electrode	Volts	Watts	Equip- ment. Refer to curves in Fig. 30	Total lumens	Lumens per watt	Mean lower hemi- spherical candle- power
4-amp. long-life.....	80-85	330	A	2,780	8.4	239
	75-80	310	B	3,190	10.3	311
	75-80	310	C	3,320	10.7	479
	75-80	310	D	3,260	10.5	450
4-amp. high-efficiency.....	80-85	330	A	4,860	14.7	413
	75-80	310	B	5,010	16.2	493
	75-80	310	C	5,320	17.2	758
	75-80	310	D	5,030	16.2	698
5-amp. long-life.....	78-83	403	A	4,620	11.5	390
	75-80	388	B	5,090	13.1	515
	75-80	388	C	5,350	13.8	770
	75-80	388	D	5,170	13.3	693
5-amp. high-efficiency.....	78-83	403	A	7,640	19.0	654
	75-80	388	B	7,260	18.7	726
	75-80	388	C	7,650	19.7	1,100
	75-80	388	D	7,260	18.7	1,017
6.6-amp. long-life.....	78-83	532	A	9,120	17.1	784
	75-80	510	B	8,800	17.3	885
	75-80	510	C	9,300	18.3	1,297
6.6-amp. high-efficiency.....	75-80	510	D	8,960	17.6	1,186
	78-83	532	E	9,670	18.2	897
	78-83	532	E	12,300	23.2	1,095

(Data from Ill. Eng. Lab., G. E. Co.)

A diagram of the connections of the magnetite-arc lamp is shown in Fig. 29. The copper electrode has sufficient size to prevent its being destroyed by the arc and yet it is not large

enough to cause undue condensation of the arc vapor. Some lamps, usually called metallic-flame lamps, were also made for a time with the magnetite electrode above, but these were relatively not so successful in performance.

The magnetite arc has met with much favor in both utilitarian and ornamental street lighting, and a greater variety of standard reflecting and diffusing equipments has been developed for it than for any other type of arc. Figure 30 shows the distribution curves of lamps with the more usual of these accessories, and Table IV gives candlepower data for the standard amperages and electrodes. It will be noted that the type of electrode—that is, whether designed for high efficiency or for long life—greatly affects the candlepower output of the lamps.

The only type of arc lamps of which installations have been made during recent years is the ornamental 6.6-amp. magnetite arc.

CHAPTER VI

ILLUMINANTS—INCANDESCENT LAMPS

When an electric current is passed through any solid conductor, the conductor gradually becomes heated to a degree depending upon its resistance and the strength of the current. With conditions such that the substance may be heated in this way until it becomes incandescent and gives out light without wasting away too rapidly, there results an incandescent lamp. In the present incandescent lamps used in street lighting, the solid conductor, or filament, consists of a coil of tungsten wire in a bulb filled with inert gas.

Drawn-wire Filaments.—In the first stages of development drawn-wire filaments were prepared only with the very greatest difficulty, but the wire can now be produced in any desired length and very uniform in cross-section. Tungstic acid in the form of a yellow powder is reduced to metallic tungsten in the form of a dark-gray powder by heating to red heat in hydrogen gas. The reduced tungsten is formed into a slug about $\frac{1}{4}$ to $\frac{1}{2}$ in. square and 16 in. long, by compressing it under high pressure. This slug which is fragile and a poor conductor of electricity is placed in a hydrogen furnace at a bright yellow heat, to strengthen it and make it a better conductor. It is then placed in an enclosed bottle, through which hydrogen is flowing, and is gradually heated to a high temperature by passing a constantly increasing electric current through it. The resulting slug is nearly pure metallic tungsten, hard and brittle. Next it is subjected to a process of heating and swaging until it forms a rod. This rod is drawn hot through special dies until it is reduced to wire of the desired size; it is now extremely ductile and has a very high tensile strength. The tungsten wire is coiled on a wire mandrel and cut to the proper filament lengths. The mandrel is then removed by dissolving it in an acid which does not attack the tungsten. After a final cleaning the filament is draped on the filament supports, clamped to the "leading-in" wires, and sealed in the bulb. The air is then exhausted and, in the case of gas-filled lamps, gas is added.

The Theory of the Gas-filled Lamp.—When the filament of a lamp is heated to incandescence, it starts to evaporate and the tungsten is gradually deposited on the bulb, blackening it somewhat. The higher the temperature at which the filament is operated, the more efficient the lamp is in converting electrical energy into light. This characteristic is evaluated in Fig. 31. At the same time, the higher the temperature the more rapid the filament evaporation.

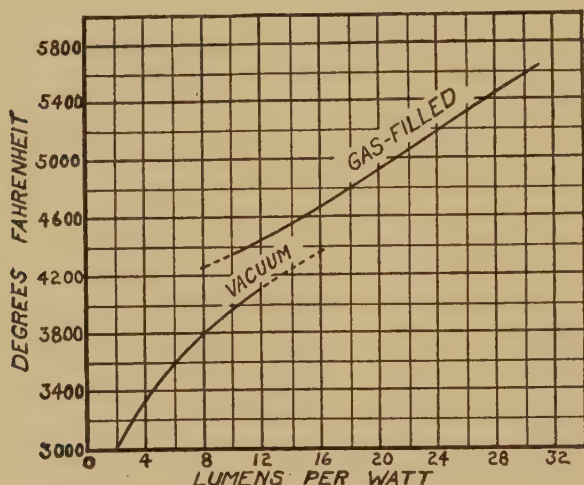


FIG. 31.—Approximate relation of filament temperature to lumens per watt.
(Data from Lamp Dev. Lab., Inc. Lamp Dept., G. E. Co.)

Since substances evaporate less rapidly under pressure, it was surmised that by exerting a pressure on the filament it could be operated at a much higher temperature, and thereby become a more efficient light producer, without increasing the rate of evaporation. However, difficulties were met. An analysis of the heat losses in the vacuum-type lamp (Fig. 32) shows that a small percentage of the heat energy is conducted away by the leading-in wires and the rest is radiated. When an inert gas—one that will not combine chemically with the material of which the filament is composed—is admitted to the bulb, new energy leaks occur through conduction and convection by the gas. Early experiments with gas-filled lamps met with failure because the conduction and convection losses were so large that the new lamps were not as efficient as the old. It was found, however,

that these losses were in proportion to the surface area of the filament and not to the cross-sectional area or volume. In other words, the loss was comparatively less in high-wattage lamps than in low-wattage lamps.

This led to the development of a new filament construction—the coiled filament. In its relation to conduction and convection, this form of filament is virtually a large filament of a cross-section equivalent to the cross-sectional area of the coils. It has been possible by means of this coiling to produce gas-filled lamps which are more efficient than the vacuum lamps in sizes as low as those designed for something less than $\frac{1}{2}$ amp.

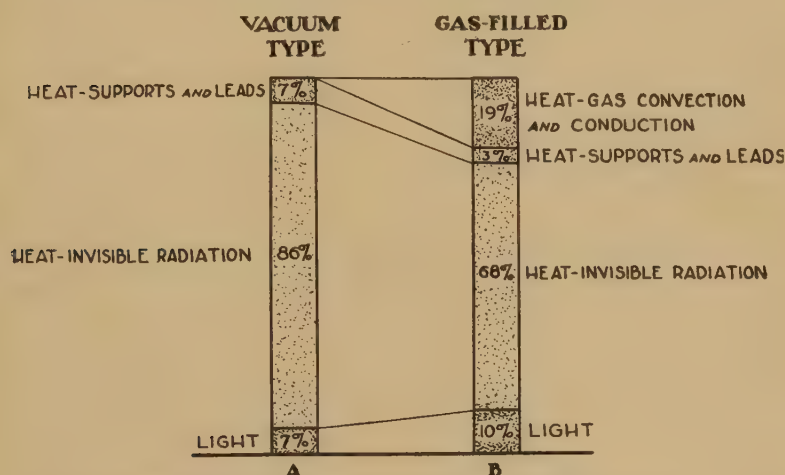


FIG. 32.—Approximate distribution of energy within 100-watt lamps. (Data from Lamp Dev. Lab., Inc. Lamp Dept., G. E. Co.)

In addition to being a more efficient generator of light, the gas-filled lamp has other characteristics which make it especially well suited for street-lighting service. The concentrated filament permits more accurate control of the light by auxiliary equipment, and the currents set up in the gas carry the evaporated tungsten to the upper part of the bulb where the blackening is least detrimental in absorbing light which would otherwise be delivered to the street. Since the filaments of gas-filled lamps operate at a higher temperature, they emit a whiter light—usually considered to be desirable.

Multiple and Series Lamps.—A large majority of the incandescent lamps employed for street-lighting service are of the series

type, although multiple lamps are coming more and more into use. The principal types and sizes of series and multiple Mazda lamps used in street lighting are given in Tables V and VI. Series circuits are rapidly becoming standardized at 6.6 amp., and by far the greatest number of the smaller street-series lamps, up to and including 2,500 lumens, are of the 6.6-amp. type.

Multiple lamps are rated in watts and are designed to operate on circuits regulated for voltage. The voltage, wattage, and efficiency at which multiple lamps are to operate determine the length and diameter of the filament.

Street-series lamps are rated in lumens and are designed to operate on circuits regulated for current. The filaments of all lamps of a given current rating are cut from wire of a diameter practically fixed for that value of current. The efficiency at which the lamps are to be operated determines this diameter, and the lumen output which the lamps are to give determines the length of the filament. The voltage is automatically fixed when the current, efficiency, and lumen output are chosen. Because their basis of rating is lumen output, improvements in Mazda series lamps are in the direction of decreasing the lamp wattage and, consequently, the voltage, without changing the current or lumen output. These features of design make it entirely practical to operate various sizes of Mazda series lamps on the same line, provided only that they are of the same current rating. So long as the proper current flows in the line, the lamps automatically take their correct voltage. If the lamps are of high current rating, as in the case of 20-amp. lamps, they may be operated on a 6.6-amp. line by means of individual current transformers.

Although the lamps used in street lighting employ a coiled filament there is practically no inductance in the filament. The power factor of a coiled-filament Mazda lamp is so nearly 100 per cent that it cannot be shown to be different by measurement. By calculation it is found that the inductance drop on a coiled-filament lamp is of the order of 0.001 volt, which value gives a power factor of about 99.9999 per cent. All inductance losses in street-lighting circuits are, therefore, due to the control and transforming apparatus, and not to the lamps.

The resistance of tungsten-filament lamps is not constant but increases rapidly as the temperature of the filament increases.

TABLE V.—PRINCIPAL SERIES MAZDA LAMPS—1,350 HOURS RATED AVERAGE LIFE—EMPLOYED IN STREET-LIGHTING SERVICE¹

Amperes	Initial lumen output ²	Average volts	Average watts	Initial lumens per watt	Bulb designation	Bulb diameter, inches	Maximum overall length, inches	Light center length, inches	Base	Position of burning
6.6	600	6.6	43.5	13.8	S-24½ clear	8½ ¹ / ₆	7½	5½	Mogul screw	Any ³
	800	8.1	53.7	14.9	S-24½ clear	8½ ¹ / ₆	7½	5½	Mogul screw	Any ³
	1,000	9.7	64.1	15.6	S-24½ clear	8½ ¹ / ₆	7½	5½	Mogul screw	Any ³
	2,500	22.3	147.0	17.0	PS-35 clear	4¾	9½ ¹ / ₆	7	Mogul screw	Any ³
	4,000	34.2	226.0	17.7	PS-35 clear	4¾	9½ ¹ / ₆	7	Mogul screw	Any ³
	6,000	50.0	330.0	18.2	PS-40 clear	5	9½ ¹ / ₆	7	Mogul screw	Any ³
15	4,000	15.1	226.0	17.7	PS-35 clear	4¾	9½ ¹ / ₆	7½	Mogul screw	Base-up ⁴
20	6,000	16.0	320.7	18.7	PS-40 clear	5	9½ ¹ / ₆	7½	Mogul screw	Base-up ⁴
	10,000	26.0	521.0	19.2	PS-40 clear	5	9½ ¹ / ₆	7½	Mogul screw	Base-up ⁴
	15,000	38.1	762.0	19.7	PS-40 clear	5	9½ ¹ / ₆	7½	Mogul screw	Base-up ⁴
	25,000	62.2	1,244.0	20.1	PS-52 clear	6½	13¾	9½ ⁵	Mogul clamp	Base-up ⁵

¹ Lamps for existing circuits of 4, 5.5, and 7.5 amp. are still supplied by the lamp manufacturers. Their lumen ratings are the same as those of the 6.6-amp. lamps.

² The nominal horizontal candlepower of these lamps is one-tenth of their lumen output.

³ Will operate in any position, but the lumen maintenance is best when burned pendent base-up.

⁴ For base-down burning, 5¼ in.

⁵ Not recommended for base-down burning; 8¼ in. when so supplied.

(Data from Manufacturer's Schedules, National Lamp Works, G. E. Co.)

TABLE VI.—PRINCIPAL MULTIPLE MAZDA LAMPS—1,000 HOURS RATED AVERAGE LIFE—EMPLOYED IN STREET-LIGHTING SERVICE

Watts	Usual volts ¹	Amperes at 115 volts	Initial lumens output	Initial lumens per watt	Bulb designation	Bulb diameter, inches	Maximum overall length, inches	Light center length, inches	Base	Position of burning
100	115	0.87	1,340	13.4	A-23 inside frost	2 $\frac{7}{8}$	6 $\frac{1}{2}$ 6	4 $\frac{3}{8}$	Medium screw	Any ²
150	115	1.30	2,310	15.4	PS-25 clear	3 $\frac{1}{8}$	6 $\frac{1}{2}$ 6	5 $\frac{1}{4}$	Medium screw	Any ²
200	115	1.74	3,280	16.4	PS-30 clear	3 $\frac{3}{4}$	8 $\frac{1}{8}$	6	Medium screw	Any ²
300	115	2.60	5,340	17.8	PS-35 clear	4 $\frac{3}{8}$	9 $\frac{7}{8}$ 6	7	Mogul screw	Any ²
500	115	4.35	9,500	19.0	PS-40 clear	5	9 $\frac{1}{2}$ 6	7	Mogul screw	Any ²
750	115	6.52	14,550	19.4	PS-52 clear	6 $\frac{1}{2}$	13 $\frac{1}{8}$	9 $\frac{1}{2}$	Mogul clamp	Any ²
1,000	115	8.70	20,400	20.4	PS-52 clear	6 $\frac{1}{2}$	13 $\frac{1}{8}$	9 $\frac{1}{2}$	Mogul clamp	Any ²
1,500	115	13.00	33,000	22.0	PS-52 clear	6 $\frac{1}{2}$	13 $\frac{1}{8}$	9 $\frac{1}{2}$	Mogul clamp	Any ²
2,000	115	17.40	45,000	22.5	{ GT-38 clear PS-52 clear	4 $\frac{3}{4}$ 6 $\frac{1}{2}$	15 13 $\frac{1}{8}$	7 9 $\frac{1}{2}$	Mogul clamp Mogul clamp	Base-down Base-up

(Data from Manufacturer's Schedules, National Lamp Works, G. E. Co.)

¹ The trend is distinctly toward 115 volts as the ultimate standard. At present, voltages of 110 and 120 are also used widely enough to warrant designating them as standard.² Will operate in any position, but the lumen maintenance is best when burned pendent base-up.

For this reason, a change in the voltage impressed on a lamp does not produce a proportional change in current. The equation $i = e^{0.54}$ expresses this relation with fair accuracy, and from this equation it is seen that a change in voltage of a given percentage will cause only about half as much change in current. Conversely, a change in current of a given percentage will result in about twice as much change in voltage.

Lamp Characteristics—Multiple Lamps.—In the multiple lamp, the impressed voltage remains constant throughout life

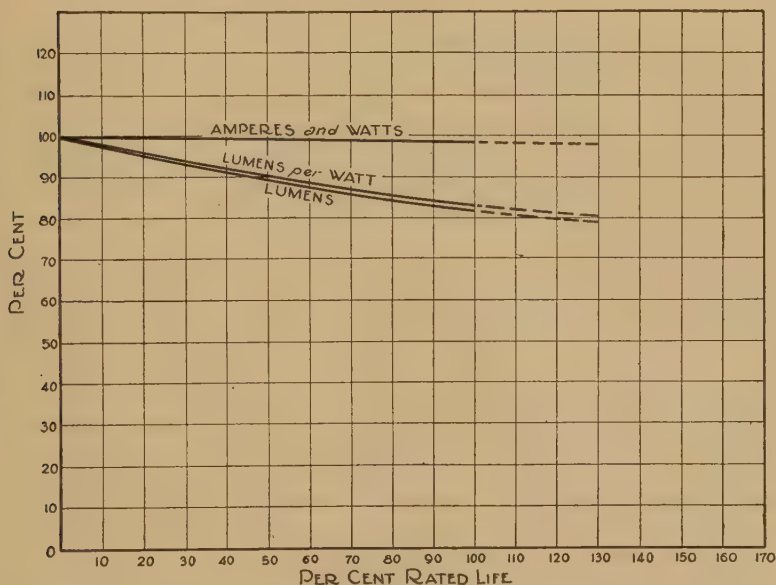


FIG. 33.—Typical operating performance of large multiple lamps. Data for the 500-watt 115-volt lamp, 19.0 initial lumens per watt.

while the resistance increases due to disintegration or evaporation of the filament; therefore, the amperes and watts of the lamp decrease slightly during life. The typical performance curves in Fig. 33 show that this decrease is about 2 per cent and the average lumens throughout life of a multiple Mazda C lamp is around 90 per cent. With the larger lamps it will be slightly less than this and with the smaller ones slightly more.

Most multiple lamps are designed for an average rated life of 1,000 hr. Burning these lamps on circuits of a voltage other than that for which they are designed seriously affects the

lumen output and life. The amperes, watts, and lumens per watt are also affected as shown by Fig. 34.

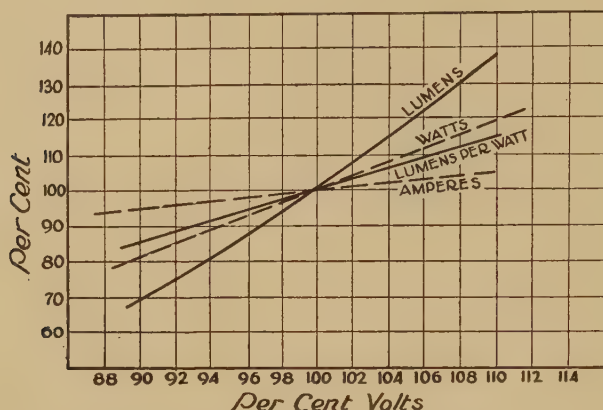


Fig. 34.—The effect of voltage on the operation of large multiple lamps. Data for the 500-watt 115-volt lamp.

The life rating of multiple Mazda lamps is determined by the average results of exhaustive tests on many groups of lamps.

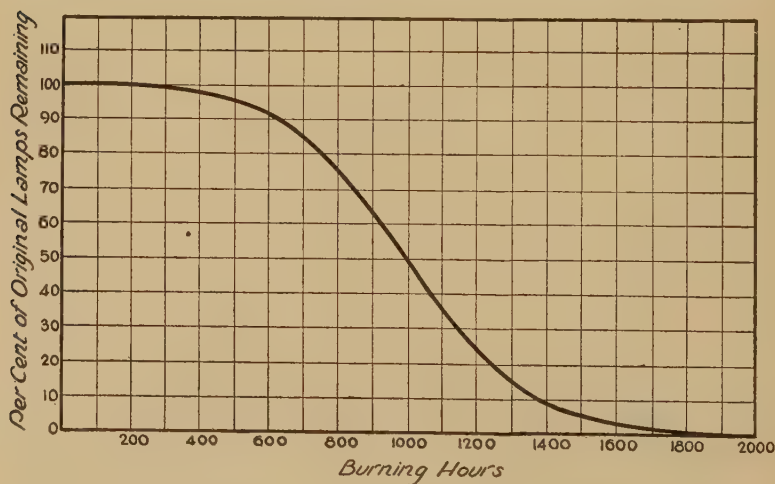


Fig. 35.—Survivor curve for the 100 lamps in Table VII.

Table VII shows the results of a typical life test on 100 lamps. These same data are presented in the survivor curve in Fig. 35. It will be noted that of the lot of 100 lamps, 50 lamps failed

before burning 1,000 hr., and 50 burned beyond that period. The curve in Fig. 36 shows the variation in rate of renewals for this typical group of lamps.

TABLE VII.—TYPICAL LIFE PERFORMANCE OF A GROUP OF 100 LARGE MULTIPLE LAMPS

Hours burned	0	200	400	600	800	1,000	1,200	1,400	1,600	1,800	2,000
Number of lamps remaining	100	99	97	91	75	50	25	9	3	1	0

Since these data are typical, qualitatively, of the average results which may be expected from all multiple Mazda lamps, it follows that in a new installation all the lamps cannot be expected to burn for the period of their average rated life and then fail simultaneously. It has been found from service experience that for a period of 3,000 to 4,000 burning hours after a new

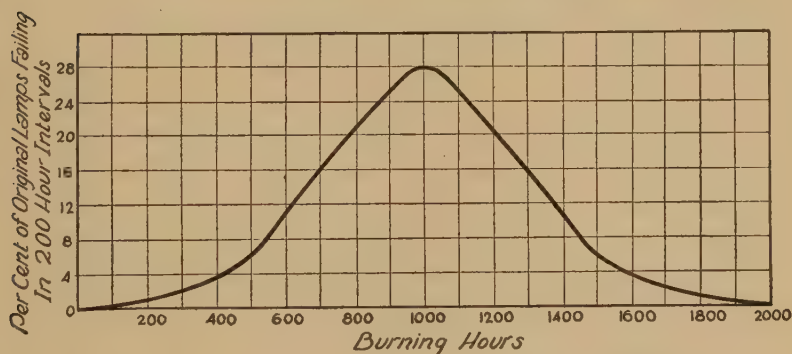


FIG. 36.—Rate-of-renewal curve for the 100 lamps in Table VII.

installation is made, there is a variation or fluctuation in the daily rate of lamp renewals (and renewals of renewals). The range of variation becomes narrower as time goes on until the rate of lamp renewals finally becomes practically constant.

This variation in the rate of lamp renewals is often attributed to irregularities in lamp quality, but analysis of the curves in Figs. 35 and 36 shows that it follows naturally from the burn-out characteristics of incandescent lamps. Obviously, the failures of the renewal lamps will occur at a somewhat later period than the failures of the original lamps. If the failures of the renewal

lamps are added to the failures of the initial lamps, it can be seen that at some time, more or less closely corresponding to the peak of the curve (Fig. 36), there will be a peak in the total renewal curve. The curve of Fig. 37 presents this phenomenon. The first peak in the total-renewal curve, which is approximately 48 per cent above normal, occurs about 1,080 average burning hours after the initial installation. Corresponding to the subsequent decline of the curve in Fig. 36, the total-renewal curve

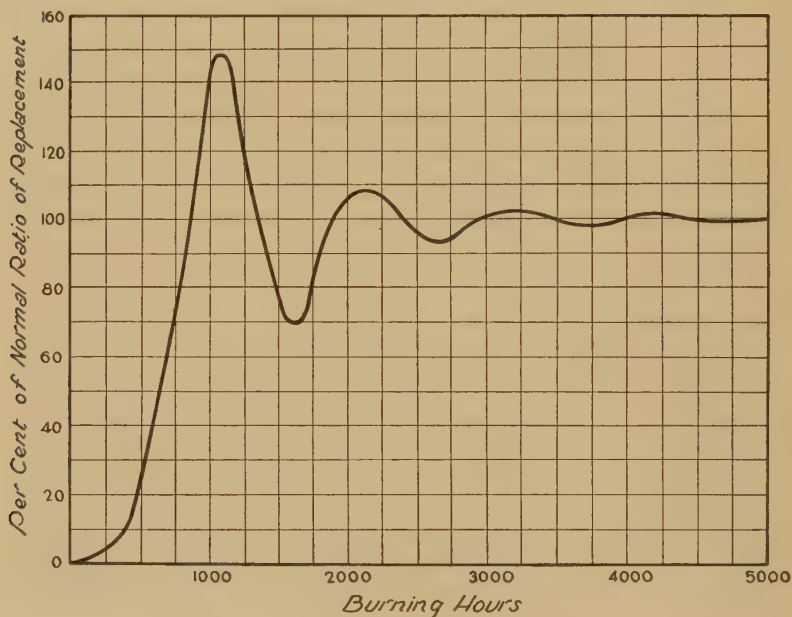


FIG. 37.—The total-renewal curve, based on the life performance given in Table VII, resembles a damped sine wave.

shows a decided decline from the first peak, indicating that the rate of renewal may be expected to decrease to about 69 per cent of its normal value at 1,620 hr. As time goes on, the oscillations of the renewal-rate curve show a decrease in range, and finally it becomes practically constant and normal.

Lamp Characteristics—Series Lamps.—The lumen output of series lamps, when burned on constant current, is maintained throughout life exceptionally well. This is due to the fact that although the bulb is slightly discolored by the evaporation of the filament, the current remains at its initial value and the increased

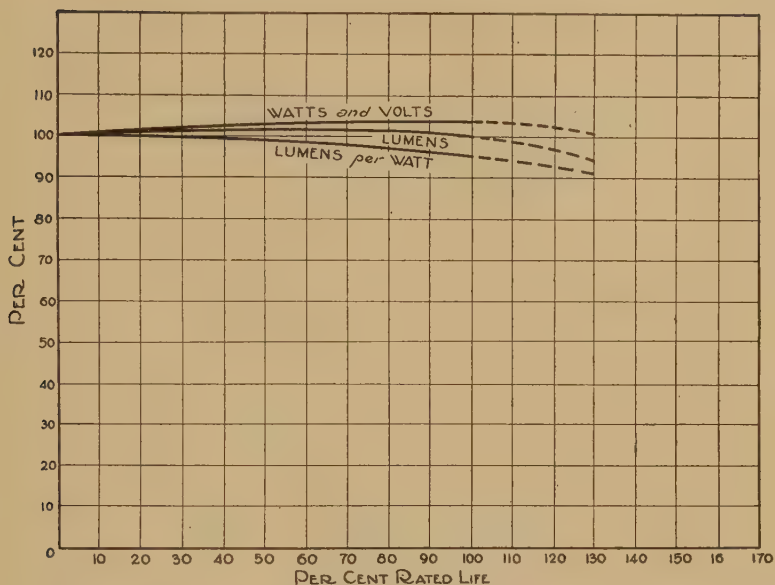


Fig. 38.—Typical operating performance of low-current series lamps. Data for the 6.6-ampere 2,500-lumen lamp, 17.0 initial lumens per watt.

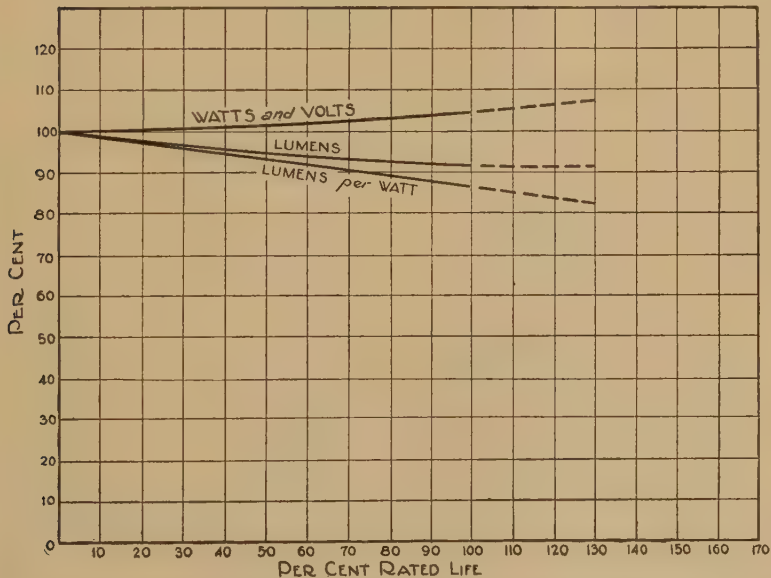


Fig. 39.—Typical operating performance of high-current series lamps. Data for the 20-ampere 10,000-lumen lamp, 19.2 initial lumens per watt.

brilliancy per unit of filament surface, because of the higher current density, maintains the lumen output very close to its initial value. Figs. 38 and 39 show the operating characteristics of series lamps.

Street-series lamps are designed for an average rated life in service of 1,350 hr. Since variations in current have about double the effect on life and lumen output as do variations in voltage, as already mentioned in connection with multiple lamps, it is highly important that series lamps operate at the

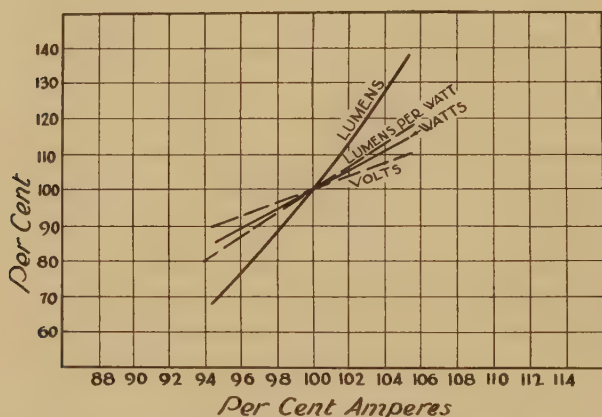


Fig. 40.—The effect of current on the operation of series lamps. Data for the 6.6-ampere 2,500-lumen lamp.

current for which they are designed. The variations in lumen output, lumens per watts, volts, and watts when burned below and above the normal amperage are shown in Fig. 40.

Precautions.—The incandescent lamp of today is a comparatively rugged device. If the best operation is desired, however, lamps should be used under the operating conditions for which they were designed. In operating incandescent lamps for street lighting it is well to have the following in mind:

1. The filaments of the lower-wattage multiple lamps are of a small diameter and, consequently, are not as sturdy as the short, thick filaments of the series lamps. If the 115-volt multiple lamps of 100 watts or less are not rigidly supported from fixed bracket arms, there is likely to be excessive filament breakage because of vibration and shock due to the wind and other

causes. Series lamps operate quite successfully when supported from trolley poles. Multiple lamps, if used in this way, should not be smaller than the 300-watt size.

2. In the operation of series lamps the constant-current regulator should be so designed or controlled that there will be no surge, either at starting or during operation, of sufficient magnitude to melt the filaments of the lamps. This problem is discussed in Chap. VIII.

3. The effect of burning lamps above and below their rated voltage and current has been discussed. Mazda lamps are designed for satisfactory and economical service at rated volts and amperes.

4. The tendency is toward the standardization of 6.6-amp. equipment for series distribution. Such standardization means that, as time goes on, transformer equipment and lamps (except in the 15- and 20-amp. class) of other than 6.6 amp. will be progressively more difficult to obtain and probably more expensive.

5. The 6.6-amp. series lamps are now being manufactured for universal burning, *i.e.*, for either base-up or base-down burning. The filament construction of 15- and 20-amp. lamps is different for the two classes of burning and successful operation is obtained only by burning the lamps in the position for which they are designed.

6. Individual lamp transformers for use on series circuits are designed to give proper secondary current over a certain range in secondary resistance. A long run to the lamp on the secondary of these transformers may increase the resistance to such an extent that the lamp will not receive proper current. The characteristics of these transformers should be studied before any departure from usual operating practice is adopted.

7. The burning of incandescent lamps in series with magnetite-arc lamps is not recommended. The arc-lamp circuit is susceptible to surges from the freezing of electrodes, tree grounds, starting, and other causes, and the constant-current regulators are, in general, not sensitive enough to eliminate these surges sufficiently for satisfactory operation of incandescent lamps. Furthermore, rectified current is a pulsating current, and its effective or heating value is somewhat higher than that of the average current as recorded by a direct-current ammeter of the usual type. For this reason, lamps designed to operate on arc circuits rated at 4 amp. must be designed for about a $\frac{1}{4}$ amp. higher current.

If it is considered necessary to burn incandescent lamps in series with magnetite arcs, care should be taken to employ lamps built for this service.

8. Series lamps are designed for operation on series circuits. A hybrid arrangement of lamps and circuits, such as series lamps on a multiple circuit, does not give a permanently satisfactory operating condition. A detailed discussion of the factors entering into such operation may be found on pages 99 and 100.

CHAPTER VII

REFLECTING, REFRACTING, AND DIFFUSING MEDIA

The use of reflecting, refracting, and diffusing media in street lighting is a fundamental of good lighting practice. Such equipments not only modify the brilliancy of the light source and diffuse the light to produce a soft and pleasing illumination, but also serve the important purpose of redirecting light, which would otherwise be ineffective, into useful angles. The use of reflecting equipment in this field, according to authentic records, dates back to Paris in the year 1745. In his paper, "Historical Sketch of Street Lighting¹," P. S. Millar describes these equipments as follows:

In 1745, 23rd of December, Matherot de Preigney and Bourgeois de Chateaublanc obtained the privilege of an enterprise for new lanterns furnished with oil and polished metal reflectors called "reverbere." Here is a development of the very highest importance in the history of street lighting!

This was followed in 1763 by another significant advance. There was held a competition at the Academie des Sciences to obtain a plan for "the best way of lighting a large city, ensuring as far as possible safety, economy, and duration." Chateaublanc won the prize with a modified and improved form of his reverbere.

The use of these reflectors in street lighting gave rise to discussions which would not be out of place in a meeting of the Illuminating Engineering Society. Chateaublanc declares in his memoirs that the light from his reverbere was so intense that a person could be recognized 30 paces away. Numbers of people, however, found the light too brilliant, and complained that it tired the eyes of passers-by and blinded coachmen and horses. Chateaublanc retorted that if some eyes were blinded by his lights it was because they gazed at them with too much admiration. It was not necessary to look at his lanterns, which were suspended 25 to 30 feet high. Their attention should be directed to their feet and surroundings. As to the coachmen, they should be looking at their horses, while the horses themselves could not easily walk with their heads in the air. Thus did this

¹ I. E. S. *Trans.*, Vol. XV, No. 3.

prototype illuminating engineer deal with the earliest discussion of glare in street lighting!

The company which was organized to light the streets with oil reverbere lanterns contracted to repair and substitute new lanterns, furnish oil of tripe, and hire the lighters, for an annual payment of about \$70,000. This street lighting, being entrusted to a company especially organized to administer it, proved satisfactory. M. Sartine says: "The light diffused by this reverbere is so brilliant that it is impossible to think that the future has in reserve anything better!" In 1780 Mercier wrote: "There have been no more lanterns for sixteen years, the reverbere have taken their place. In former times 8,000 lanterns with badly placed candles, extinguished by the wind or melted, lighted badly or gave a pale, uncertain light interspersed by shadows, shifting and dangerous. Today means have been found to give great light to the city and also great facility of service."

In 1777 the road from Paris to Versailles was permanently illuminated. Five leagues and a half of reverbere. Never had such an illumination been imagined. Mercier exclaimed: "No city, ancient or modern, has offered utility on such a scale!"

Following is a specification of the earlier reverbere: Hexagonal frame of iron without solder. Those of five lights shall be 2 ft. 5 in. in height including the cap. Diameter, 22 in. at the top and 16 in. at the base. Those with three or four lights must be 26 in. high including the cap. Those with two lights will be 24 in. in height, 17 in. in diameter at the top and 9 in. at the base. All the lanterns shall have their lamps of different sizes in proportion to the time they will be lighted. Each light shall have a reflector of copper, silver plated, and each lantern shall have a reflector placed horizontally over the light which shall be the whole size of the lantern to prevent shadows. This reflector shall also be of copper, silver plated.

At the end of the eighteenth century there were 5,624 reverbere in Paris. These continued in use until displaced by gas lamps.

The authors have included the above quotation at length, not only because of its general interest but also because it emphasizes the fact that about two centuries ago the advantages of combining auxiliary equipment with the light source as a method of controlling the distribution of light was given important consideration.

Light Control.—A beam of light will travel along a straight line indefinitely until it is modified or redirected by some external agency. Such modification may be in the nature of *absorption* by

the medium through which it passes or by the object upon which it impinges. This is noticed when a beam of light passes through a smoky atmosphere, through a piece of smoked glass, or meets a black opaque body. In these cases, a part or practically all of the light loses its identity as such and is converted into heat. A second form of modification is termed *refraction*. Refraction is a bending of a ray of light due to its passing from one transparent medium to another of greater or less density, as, for example, from air to water or from air to glass. A very common instance of refraction is the apparent bending of a fish line at the point where it enters the water; as a matter of fact, the line is straight but the light rays coming from that part of the line which is under the water are refracted when they pass from water into air. A third form of modification of a beam of light is *reflection*, which is the throwing back or redirection of the rays by a surface. A fourth form is *diffusion*, which is the breaking up of the beam and spreading of its rays in all directions by the medium through which it passes or by the surface upon which it falls. By means of these four methods—absorption, refraction, reflection, and diffusion—it is possible to control the light from any source practically as desired.

Polished-metal and Mirrored-glass Reflectors.—The simplest form of reflection is that which takes place when a ray of light strikes a polished-metal surface. As indicated in Fig. 41, a ray of light having a direction *sa* on striking a polished-metal surface

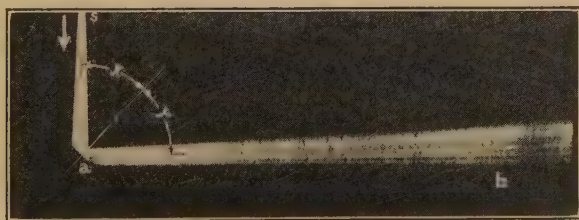


FIG. 41.—Reflection from polished metal.

is reflected off in the direction *ab*, so that the angle *Y* (called the angle of reflection) is equal to the angle *X* (called the angle of incidence) and practically no light is reflected in other directions. This is called “regular reflection.” It will be seen, therefore, that it is possible to redirect light traveling in a given direction into any other desired direction by means of such a surface

properly placed. When we consider that the schoolboy, by means of a pocket mirror or piece of polished metal, can take the beam of sunlight that comes in at the window and redirect it with remarkable accuracy to any place in the room, the general principle involved is seen to be simple.

While all polished-metal surfaces reflect light in the manner described, they do not reflect it in like amounts. For instance, if two beams of 100 lumens each fall, respectively, on a polished-silver surface and on a polished-aluminum surface, the silver will reflect a little less than 90 lumens and the aluminum about 60 lumens. In other words, the silver surface will absorb about 10 to 12 per cent and the aluminum will absorb 35 to 40 per cent. All of the light falling on an opaque surface is either reflected or absorbed by that surface.



FIG. 42.—Reflection from a mirror.

Similar to the reflection characteristics of polished metal are those of mirrored glass. Fig. 42 shows the path of a ray of light striking the surface of a commercial type of mirror with silvering on the back of the glass. A small part of the light is at once reflected by the polished surface of the glass without passing through to the silvered backing; the remainder passes through the glass to the silver, from which it is reflected through the glass again and out along a line parallel to the ray reflected from the glass surface. The fact that most of the light has to pass through the glass both to and from the reflecting surface makes the silvered mirror, from a laboratory standpoint, a less efficient reflecting surface than the polished silver itself. For instance, if 100 lumens strike a mirror the reflections and absorptions are of the following order of magnitude: 10 lumens are reflected by the exposed surface of the glass, 10 are lost by being absorbed by the silvered surface, 5 or more are absorbed by the

glass, and about 75 lumens are reflected by the silvered surface, making a total output of about 85 lumens. The deterioration of an unprotected silvered reflecting surface in service is, however, a factor which more than offsets its higher initial efficiency. In the field of metal reflectors, the merit of chromium plate is that although its initial efficiency—about 65 per cent—is considerably lower than that of silver-plated metal this efficiency is very well maintained in service.

To obtain a desired distribution from a polished-metal or a mirrored surface, it is necessary that the contour of the reflector at each point be such that it makes equal angles with the incident ray at that point and the desired direction of light. For example,

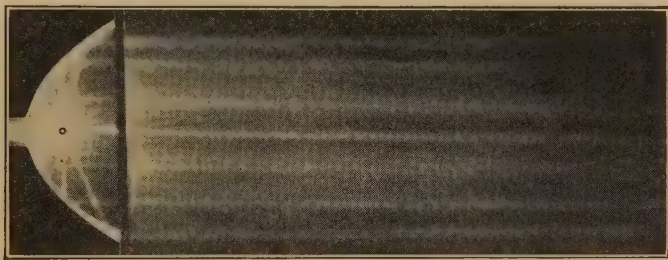


FIG. 43.—Accurate light control is obtained with polished-metal or mirrored surfaces.

where essentially parallel rays of light are desired, as in the case of automobile headlights, the cross-section of the reflector must be curved so that the elements or infinitesimal planes of the curve each reflect light as a plane surface, in the desired direction. The resulting curve is the parabolic reflector (Fig. 43).

On the other hand, a reflector of hemispherical shape placed above the lamp, with its center coinciding with the light source, will not concentrate the light into a beam; instead, it will nearly double the candlepower at each angle in the lower hemisphere, since each ray that strikes the reflector is reflected back along the same line, through the source and into the lower hemisphere.

In street lighting, mirrored reflecting surfaces have been used in various devices intended to concentrate the bulk of the light from the lamp within the boundaries of the street, and to intensify the illumination at points midway between the units. Many patents have been issued on equipments of this type; two such devices are shown in Fig. 44. Equipments of this general

character have not attained widespread use in America, due primarily to the sensitivity of adjustment and the almost total failure of the units if the reflecting surfaces become coated with dust or tarnished.

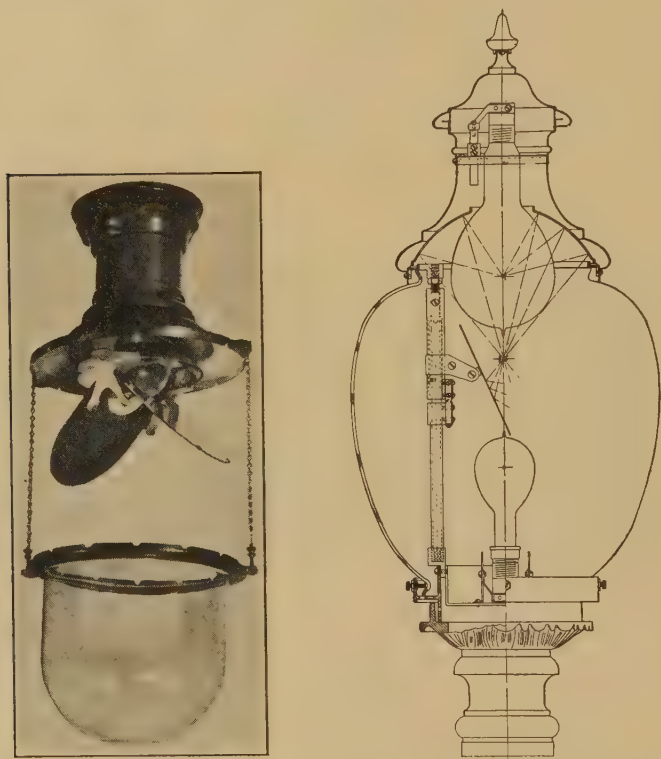


FIG. 44.—Street-lighting equipment employing mirrored reflecting surfaces.

Dull-finish Metal Reflecting Surfaces.—A dull-finish metallic reflector can be considered as one which has many small polished surfaces making innumerable slight angles with the contour. A velvet-finish nickel surface or one coated with aluminum paint affords a good example. When a shaft of light strikes such a surface, the individual rays are reflected at slightly different angles, but all in the same general direction. This is known as “spread reflection.” The spread of the reflected beam is dependent upon the degree of smoothness of the surface—the smoother the surface, the narrower the reflected beam. When

the reflecting surface is viewed along the line *ba* (Fig. 45) no distinct image of the light source but only a bright spot of light is visible. Dull-finish reflectors redirect the light with less concentration than do polished reflectors, but at the same time, streaks and striations are largely eliminated. The greatest objection to this type of surface for outdoor use lies in the fact that it collects dust and dirt quickly and is therefore difficult to keep clean.

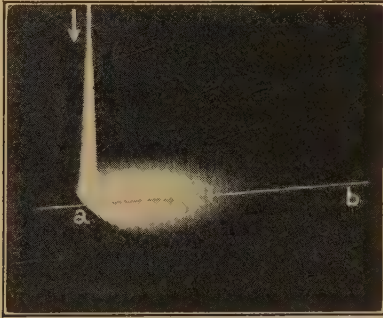


FIG. 45.—Reflection from a dull-finish surface—aluminum paint.

The more common materials for dull-finish reflectors are spun aluminum and aluminum-finish metal. Both of these surfaces have been used in street-lighting equipments, but usually simply to diffuse and not to control accurately the distribution of light. Oxidized aluminum is a better reflector than either.

White or Milk-glass Globes.—White (loosely termed “opal”) glass has found considerable application in street-lighting practice. The properties of white glass may be most readily understood if we regard it as ordinary glass in which fine white particles are held in suspension. When a beam of light strikes a piece of white glass, 10 to 15 per cent of it is reflected at once from the polished surface of the glass without entering the glass at all. The remainder travels through the glass until it strikes the white particles whence it is dispersed in all directions, some of it being thrown back and reflected, as shown in Fig. 46.

If any light ray passes through the glass without striking a white particle, it continues in the same direction. When this occurs, the white glass is not completely diffusing, and if, for example, it is in the form of a globe, the outline of the lamp filament can be seen more or less clearly. This condition will be

present even though only 1 per cent of the light passes through undiffused, as shown in Fig. 47.

In an enclosing globe of white glass the glass should have the maximum transmission possible without revealing the outlines of the light source. This limits the direct transmission of light

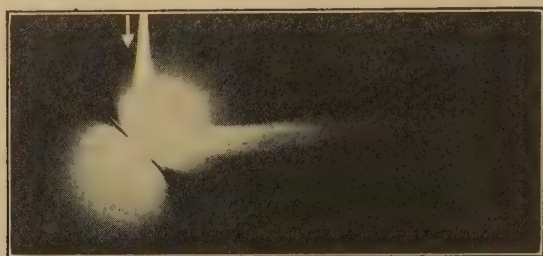


FIG. 46.—Reflection and transmission by white or milk glass.

to about 50 to 60 per cent for any one ray, but a white-glass ball globe may have an overall output as high as 85 per cent; while only 50 or 60 per cent of the light coming from the lamp may be transmitted directly through the glass, sufficient light may come from the interior by cross-reflection to bring the output up to 80 or 85 per cent.

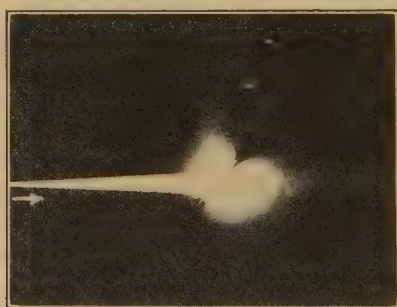


FIG. 47.—Reflection and transmission by a very light sample of white glass.

One expects a white-glass globe to appear equally bright all over, which means that each square inch of visible area emits the same candlepower. It follows, therefore, that the only way to augment the candlepower from a white globe in any particular direction is to increase relatively the area of the globe surface when viewed from that direction. In street lighting it is usually desired to obtain the highest candlepower values at angles just

below the horizontal, and for this purpose a globe having a contour such as *A* (Fig. 48), is preferable to *B*. For the same total area of glass, *A* presents a relatively greater surface when viewed from the horizontal. It will be noted from the distribution curves that although the total light output of the two globes is approximately the same, the candlepower at 75 deg. is 23 per cent greater for *A* than for *B*. These distribution curves

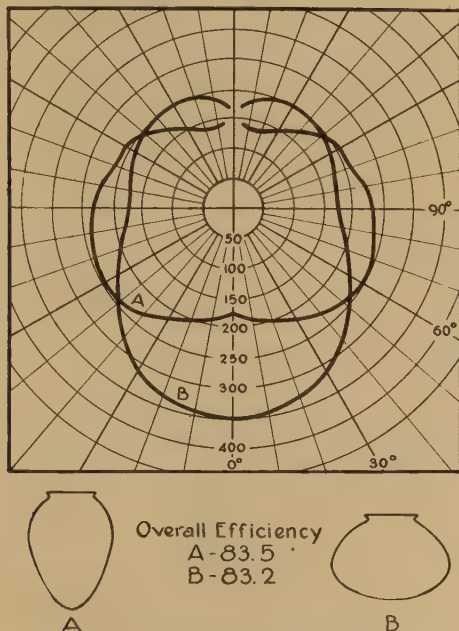


FIG. 48.—The influence of contour on the light distribution of white-glass globes.

illustrate about all the light control that can be obtained from white-glass globes. A ball globe falls about midway between these two.

Porcelain-enamel Reflectors.—In the familiar porcelain-enamel reflector, the surface, so far as its optical characteristics are concerned, can best be considered as a plate of white glass in optical contact with a steel backing. The glass must be very dense so that as little light as possible will pass through, for all the light that penetrates to the steel backing is absorbed and, therefore, wasted. Porcelain enamels vary considerably in efficiency; if of two reflectors one appears gray in comparison

to the other, it is sure to be considerably lower in efficiency. Fig. 49 shows the characteristic reflection of a porcelain-enamel surface on steel.

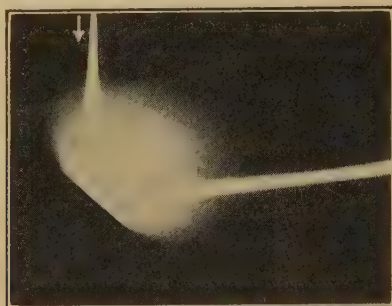


FIG. 49.—Reflection from porcelain-enamelled steel.

Probably the first thing that is noticed in Fig. 49 is the beam of regularly reflected light. This is simply specular reflection from the glazed surface, and, as in the case of white glass or glossy paint, does not ordinarily amount to more than 5 to 15 per cent of



FIG. 50.—Inverted cone of paraboloidal contour.

the incident light. By far the greater proportion is diffusely reflected as shown and, therefore, light control by means of porcelain-enamel reflectors is subject to serious design limitations. Laymen have frequently been deceived by the shininess of

porcelain enamel into believing that light would be about as readily controlled by it as by a mirror. Consequently they have often been disappointed in the results.

One of the earliest types of reflectors used with incandescent lamps in street lighting was the so-called "inverted cone of paraboloidal contour," (Fig. 50). The theory of this design was that the paraboloidal contour would concentrate all of the reflected rays at an angle of approximately 80 deg. Since the reflecting surface was nearly always of porcelain enamel, however,

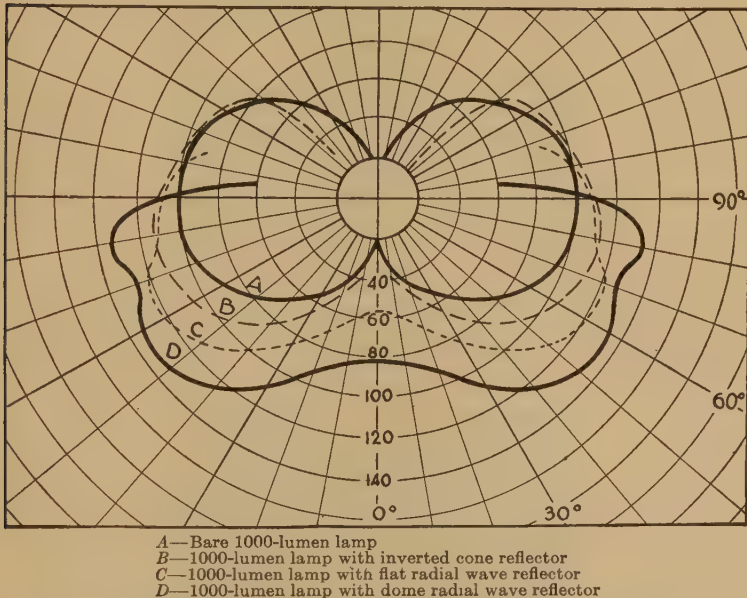


FIG. 51.—Distribution curves of early street-lighting units equipped with porcelain-enamel reflectors. (Data from *Ill. Eng. Lab.*, G. E. Co.)

the concentration was extremely slight, as indicated by curve B of the distribution curves in Fig. 51. The upward sweep of the surface allowed considerable light to escape unused in the upper hemisphere so that a simple horizontal reflecting surface would probably have been superior from a practical street-lighting standpoint.

The next development was the flat radial wave reflector, (Fig. 52). It intercepted nearly all of the upward light and secured some concentration below the horizontal, as shown by curve C in Fig. 51, by providing radial flutes from which some of

the rays were specularly reflected in the desired direction. A further improvement made practicable by the introduction of the



FIG. 52.—Flat radial wave porcelain-enamel reflector.

concentrated filament of the gas-filled lamp was the dome or bowl radial wave reflector, in Fig. 53. Curve *D* in Fig. 51 gives the light distribution of this equipment.

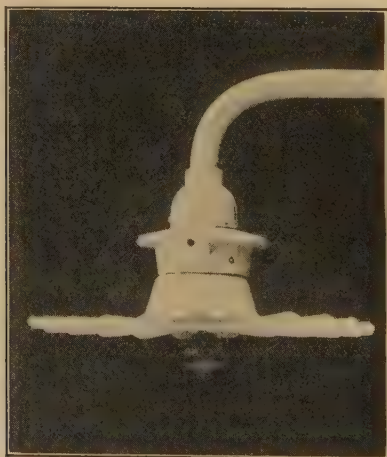


FIG. 53.—Dome radial wave porcelain-enamel reflector.

Efforts to concentrate the light in directions up and down the street resulted at an early date in designs such as in Fig. 54.

Here again the small percentage of specular reflection from porcelain enamel tended to minimize the anticipated result and although the candlepower values in a very narrow beam looked



FIG. 54.—Early porcelain-enamel reflector intended to concentrate the light up and down the street.

high, not more than 5 per cent of the total lumens of the lamp were in the beam.

Prismatic Glassware.—When a beam of light strikes a plate of glass perpendicularly, about 4 per cent of the rays are reflected

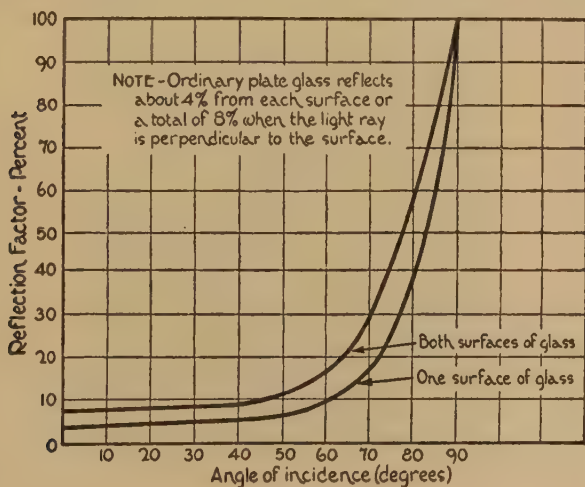


FIG. 55.—Reflection of light from clear plate glass; the angle of incidence is measured from the perpendicular, as *X* in Fig. 41. (Data from *Lamp Dev. Lab., Inc. Lamp Dept., G. E. Co.*)

from its upper surface, 3 to 4 per cent are reflected from its lower surface, about 5 to 8 per cent are absorbed by the glass, and the remainder, about 85 per cent, is transmitted.

When light strikes glass obliquely two phenomena occur: first, the percentage of light reflected from the upper surface increases

markedly so that at very oblique angles very little is transmitted and nearly all is reflected as shown in Fig. 55; second, light rays in passing into the glass are bent toward the perpendicular. Conversely, when light rays pass from glass to air they are bent away

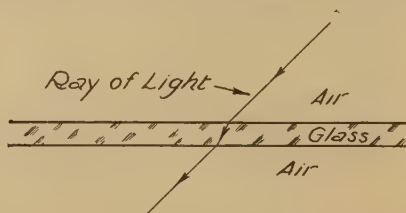


FIG. 56.—A ray of light passing through a plate of glass is bent in this manner.

from the perpendicular. Hence, if a plate of glass has parallel sides, the path of a ray of light through it is as shown in Fig. 56. In leaving the glass, the ray is bent as far from the perpendicular as it was bent toward it on entering. In case the two sides of the glass are not parallel, the result is indicated by Fig. 57.



FIG. 57.—Refraction by a prism.

It will be seen from these illustrations that the light ray is bent through a considerable angle by this glass wedge or prism, and it is upon this principle that nearly all prismatic devices for controlling the light distribution of street lamps are based. There is a very definite limit to the angle through which a ray of light can be bent using a single prism, and if this limit is exceeded the ray will be totally reflected by the inner surface of the prism and will not pass through at all.

With the introduction in 1915 of the gas-filled lamp and its more concentrated filament, the application of prismatic refractors to street lighting at once attracted general interest. Due to the wide spacing of street lighting units, a high candlepower at angles just below the horizontal had always been considered the desirable distribution of light, but in practice it had been most difficult to obtain. The refractor provided this desirable distribution and also effected a marked increase in utilization of light by redirecting the upward rays downward. The refractors

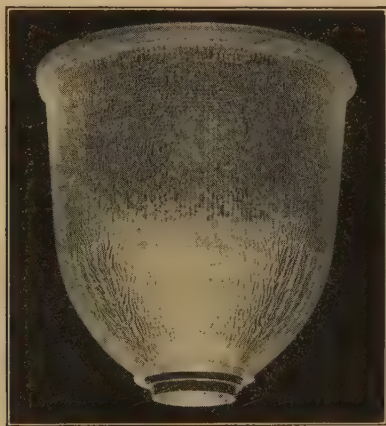


FIG. 58.—Bowl refractor, rippled, asymmetric distribution. (Courtesy of Holophane Co.)

could also be designed to give non-symmetrical or “asymmetric” distribution in a horizontal plane—that is, with such equipment it was possible to redirect into the street proper light which would otherwise fall on the abutting property. This latter possibility was never adopted extensively until recent years when the rigid mounting of units from fixed brackets or upright posts made its application feasible.

The first refractor was the so-called “bowl type” (Fig. 58) which is still used extensively today. A novel feature of this refractor was its two-piece construction, with bending prisms on the outer surface of the inner member and diffusing prisms on the inner surface of the outer member. The two members were locked together in such a way as to render it practically impossible for any dust to reach the prisms.

At the time of the introduction of the bowl refractor, street-lighting units themselves were far from dust-tight and bug-proof, and, as regular cleaning schedules were unusual, the loss of light caused by the collection of bugs and dust between the lamp bulb and the refractor was serious. This depreciation of the bowl-refractor installations in service led to the early development of the band refractor (Fig. 59) which was almost impervious to bugs and dirt, at least as far as the direct light below the horizontal was concerned. Another requirement which led to the development of the band refractor was the desire to have more light under the unit to give a bright area on the street against which objects could be silhouetted. Silhouette as a factor

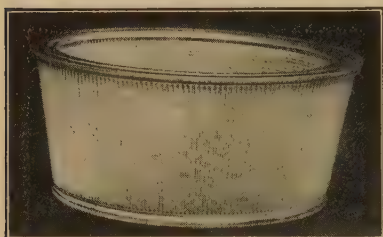


FIG. 59.—Band refractor, symmetrical distribution.

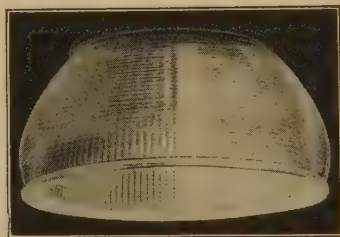
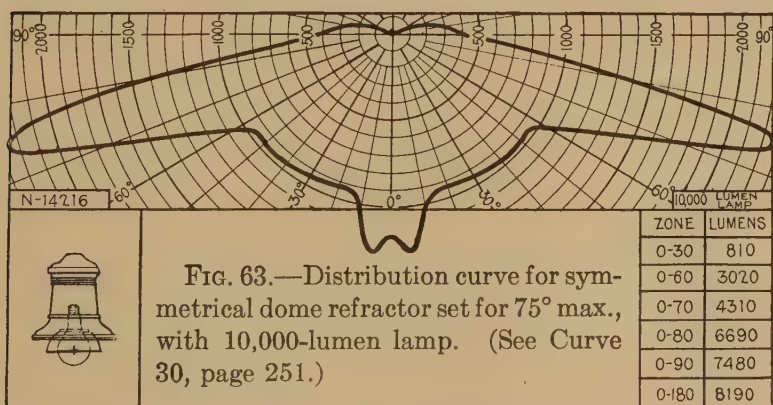
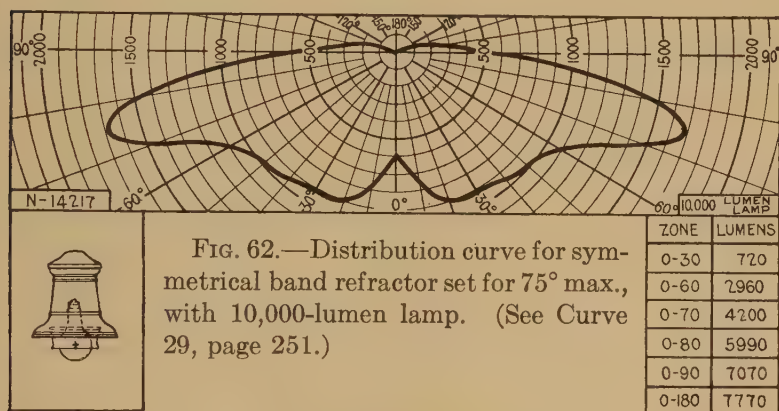
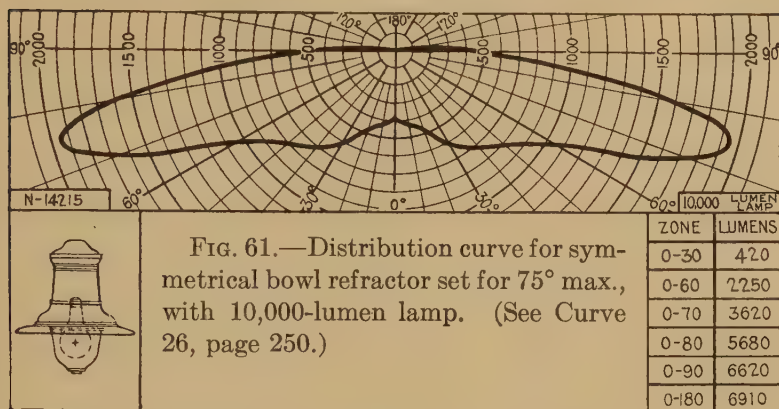


FIG. 60.—Dome refractor, asymmetric distribution.

affecting visibility on the street is discussed in Chap. X. Figures 61–63 present distribution curves for bowl and band refractors, and also for the dome refractor described on page 72. These curves are for refractors which have a symmetrical distribution of light about the vertical axis.

High brightness had from the first been a serious objection to the use of the prismatic refractor. One solution lay in increasing the size, but this multiplied the cost and consequently even today little progress has been made in this direction.

Realizing the limitations of refractor size, the idea was engendered that if the refractor were placed inside an enclosing globe of white glass, the light utilization of the refractor could be retained and the good appearance and low brightness of the globe combined with it. This was tried but it was found, as one could readily foresee from a study of the properties of white glass, that the white glass largely negated the light-directing qualities of the refractor and the net result was a loss of light equal to the



amount absorbed by the refractor. The distribution curves on page 245 illustrate this point.

The use of a ground-glass globe instead of white glass would have preserved the refractor distribution to a considerable extent, but long experience with ground-glass ball globes for street lighting had proved the impracticability of this material due to its rapid depreciation from dirt and the great difficulty of cleaning.

After considerable experiment with ice-etched and similar glasses in the Engineering Department photometric laboratory at Nela Park, it was determined that a combination of the refractor with an enclosing envelope of pressed pebbled or stippled glass with or without a small amount of opal offered an almost ideal solution. The diffusion of the light—that is, the apparent size of the source—was greatly increased but the characteristic refractor distribution was not materially affected. The first installation of this equipment, in the form of a lantern designed for the ornamental street lighting system in Cleveland,¹ was soon followed by its application to pendent units.

The band refractor was first used in installations of this type. An opportunity for improvement in efficiency over the band refractor remained, however, in that a considerable proportion of the upward light was not intercepted by it. The dome refractor (Fig. 60) embodied this improvement, but in order to bend down the rays emitted at high angles, it was found necessary to place redirecting prisms on both members of the refractor. This procedure of necessity eliminated the diffusing prisms, but these were not needed, as the dome refractor was intended primarily for use within a lantern or stippled enclosing globe which supplied the necessary diffusion.

Rippled Glassware.—Pebbled or stippled glass panels are standard for lanterns at the present time, but practical objections to stippled globes are the weight of the pressed glass, its cost, and the limitation which it places on globe contour. Halvorson found that practically the same lighting effect could be obtained by using a blown globe having a rippled outer surface, provided the glass was made sufficiently thick so that its inner surface would not follow the corrugations of the mold. Rippled glass globes are blown in iron molds and consequently their cost is comparatively low. At the same time they are quite satisfactory from

¹ HARRISON, W. "The Cleveland Lantern for Ornamental Lighting," *Electrical World*, Sept. 4, 1915.

the standpoint of cleaning as the ripples are not deep or sharp. These globes give to the light source a pleasing life and sparkle, and permit the use of refractors of either the symmetrical or asymmetrical types with practically the same result as when stippled glass is used. Pages 246 and 247 show the light distribution with a clear rippled globe and also with a light-opal flashed rippled globe, both equipped with the same inner refractor.

The light-opal flashing cuts down the maximum candlepower somewhat and is more pleasing for ornamental installations, since it reduces the intrinsic brilliancy and fills the globes with light more uniformly. There is also a field for opal flashed rippled globes without refractors, where control of light is not required. Here the medium-flashed glassware is generally to be recommended.

Candlepower Distribution Curves.—The candlepower distribution curves of representative equipments are shown on pages 242–264. No isocandle curves of asymmetric light distributing units have been included here, but a representative curve of this type is presented in Appendix *B*.

CHAPTER VIII

SERIES SYSTEMS AND THEIR CONTROL

The distinguishing characteristic of series street-lighting systems is that the same current flows through all of the lamps on the circuit. The principal reasons for the adoption of the series circuit were:

1. When electric street lighting was first introduced it was almost entirely arc lighting. The arc lamp is inherently a constant-current device and consequently gives its best operation and greatest efficiency on the constant-current series circuit.

2. In many cases, the street lighting antedated the general use of electricity in residences by a considerable period; the series circuit is the most simple and efficient method of supplying energy to comparatively small units sparsely located over a wide area.

3. A separate system of distribution furnishes a convenient means of lighting and extinguishing street lamps from the central station.

All series circuits require some means of controlling the current. The principal end sought in the design of transformers and auxiliary apparatus is to hold the current constant within narrow limits under any and all conditions. There are many types and variations of such circuits, and a discussion of the mechanical and electrical constructional features of the apparatus employed may be found in treatises on electrical machinery. It is intended here to dwell only on those characteristics of the circuits which have a direct bearing upon the performance and operating cost of the lighting units with which they are used.

Direct Current.—Two distinct methods of producing a constant direct current have found wide application in supplying series street lamps. The first of these was a constant-current generator, the familiar Brush-arc machine (Fig. 64) driven originally by a steam engine and later by a direct-connected synchronous motor. The second is a mercury-arc rectifier (Fig. 65) designed to convert a constant alternating-current supply to direct current.

The Brush-arc machines are today of historic interest only, for practically all of them have been replaced by alternating-current systems or, where direct current is desired, by the mercury-arc rectifier equipment. For at least 20 years after 1879, however, when the first electric street lamps were put in service, 6.6- and 9.6-amp. constant direct-current generators were the only practical source of electrical supply for series circuits.

The principal use of the more modern rectified current series circuits has been for the operation of magnetite-arc lamps. A constant-current transformer, which is a part of the equipment,

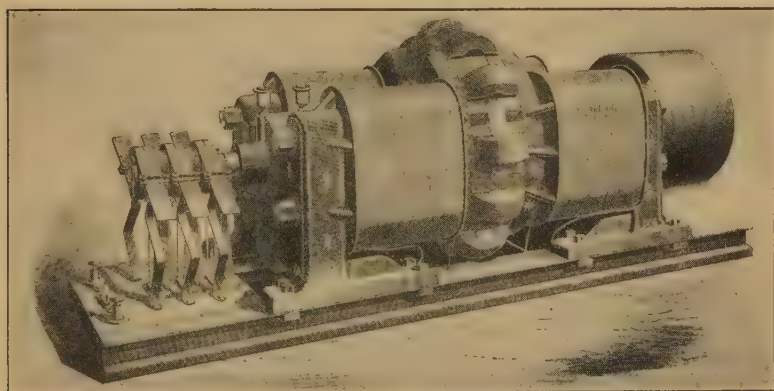
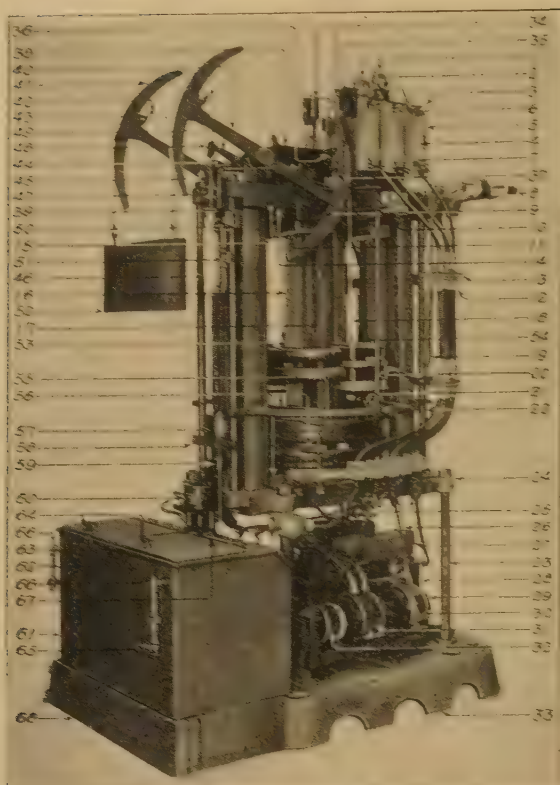


FIG. 64.—Brush direct-current generator made about 1880 and having a capacity of forty-five 2,000-candlepower arc lamps. (*Courtesy of Brush Laboratories Co.*)

supplies alternating current of constant amperage and the rectifier converts it to a pulsating direct current. The most usual current ratings are 4 and 6.6 amp., and the rectifiers are built in sizes to supply 25, 50, or 75 lights. The lamps require from 70 to 80 volts each, hence the circuit voltage falls between 2,000 and 6,500 volts. Particularly for the high voltages required by the 75-light outfits, two rectifier tubes are usually operated in series, for it has been found that this practice markedly decreases the frequency and expense of tube renewals. The rated life of tubes is 400 to 1,000 hr., and in service this latter figure is usually equaled or exceeded. Electrical data for the various sizes of mercury-arc rectifiers at present in general use with magnetite-arc lamps are given in Table VIII. It will be noted that at full load the efficiency of these outfits averages close to 90 per cent and the power factor is about 65 per cent.



1. Pilot or indicating lamp. 2. Socket for pilot or indicating lamp. 3. Static discharger.
4. Static discharger resistance base. 5. Static discharger resistance rod. 6. Static discharger horn gap. 7. Static discharger spark gap. 8. Outgoing terminal. 9. Exciting coil. 10. Cutouts for exciting coil. 11. Buffers. 12. Porcelain bushings. 13. Cable support. 14. Top clamp. 15. Top clamp set screw. 16. Core. 17. Core clamp.
18. Supporting cable. 19. Flexible connection cable. 20. Guide rod. 21. Guide rod support. 22. Upper side rod. 23. Lower side rod. 24. Bottom clamp. 25. Cable couplings.
26. D-c. reactance core. 27. D-c. reactance clamp. 28. D-c. reactance coil. 29. Exciting transformer. 30. Exciting transformer reactance coil. 31. Exciting transformer secondary coil. 32. Exciting transformer primary coil. 33. Base. 34. Underload series relay operating coils. 35. Underload series relay contact for alarm circuits. 36. Underload series relay contact for shaking circuits. 37. Underload series relay terminal. 38. Motor-operated contact. 39. Motor-operated contact terminals. 40. Balancing lever.
41. Adjusting sector. 42. Adjusting screw. 43. Check nut. 44. Shaft. 45. Mechanical latch. 46. Dashpot. 47. Dashpot rod. 48. Dashpot rod head. 49. Dashpot lever. 50. Dashpot support. 51. Dashpot by-pass. 52. Hanger or regulating weight. 53. Primary coil. 54. Primary coil clamp. 55. Secondary coil. 56. Secondary coil clamps and supports. 57. Shaking magnet. 58. Shaking magnet support. 59. Calibrating weight. 60. Oil circulator. 61. Tube tank. 62. Tube tank cover. 63. Tube tank lid. 64. Tube tank latch. 65. Valve for controlling flow of water. 66. Thermometer wells for observing temperature of water. 67. Thermometer for observing operating temperature. 68. Removable base end.

FIG. 65.—Mercury-arc rectifier, with cover removed. (Courtesy of G. E. Co.)

Sometimes it is desired to operate incandescent lamps in series with magnetite arcs on a rectifier circuit, but the results usually prove unsatisfactory and the practice is not to be recommended. Fluctuations in current which occur just prior to the time of the tube failures are likely to cause premature burnout of the incandescent lamps, and even under ordinary operating conditions, as the equipment is less sensitive than the tub transformers employed on alternating-current circuits, current fluctuations are more frequent and severe.

TABLE VIII.—DATA ON SERIES MERCURY-ARC RECTIFIER SETS

Cycle	Light capacity of set	Approximate kilowatt capacity ¹	Efficiency				Power factor			
			100 per cent load	75 per cent load	50 per cent load	33 per cent load	100 per cent load	75 per cent load	50 per cent load	33 per cent load
60	25	13.5	88	85	79	72	64	50	35	25
	50	27	90	87	81	76	65	50	35	25
	75	40	91	88	84	77	64	49	35	25
25	25	13.5	86	83	76	68	65	50	35	26
	50	27	88	85	79	71	66	51	36	27
	75	40	90	87	82	76	65	50	36	25

(Data from G. E. Co.)

¹ 6.6-amp. sets.

Alternating Current.—Alternating-current series circuits are today used almost exclusively in the operation of series incandescent lamps. There are four different types of such circuits:

1. Circuits supplied from constant-potential alternating current by means of moving coil constant-current tub transformers of types suitable:

(a) to be placed within the power station (Figs. 66 and 67), or

(b) to be placed out-of-doors underground (Fig. 68), or on poles (Fig. 69), wherever constant-potential alternating current is available.

2. Circuits supplied by moving-core automatic series reactances, the latter being usually provided with auxiliary constant-potential transformers to insulate the circuit from the main source of supply.

3. Circuits supplied from constant-potential alternating current without any auxiliaries whatsoever other than a constant-

potential transformer, the purpose of which is to insulate the circuit from the main source of supply.

4. Circuits supplied from a constant-potential transformer of high reactance equipped with taps to provide a range of voltages. In nearly all cases these systems also utilize a reactance placed in multiple with each lamp on the circuit.

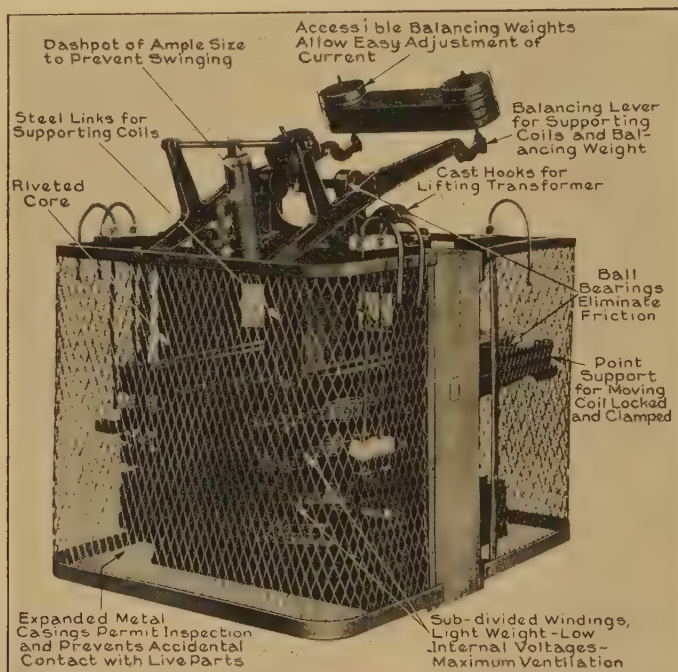
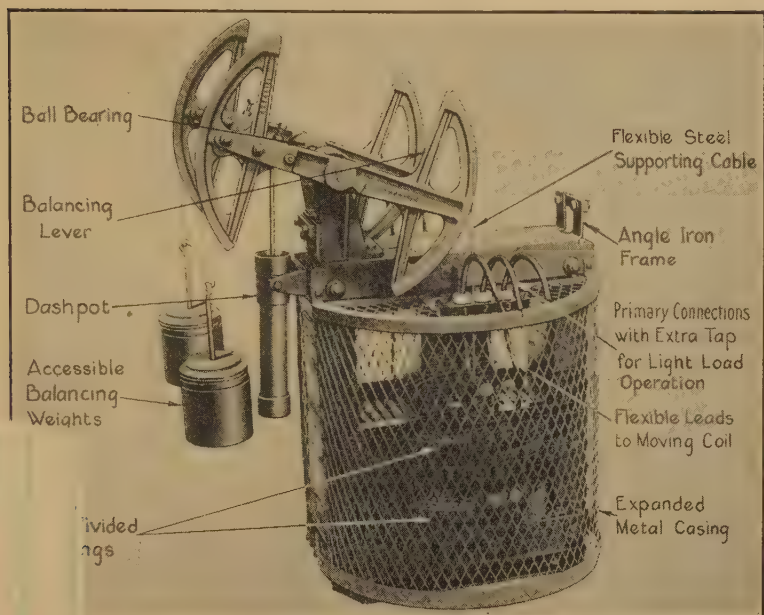


FIG. 66.—Automatic station-type RF constant-current transformer. (Courtesy of G. E. Co.)

Constant-current Transformer Circuits.—Variations in voltage on the primary circuit are completely compensated for by the constant-current transformer, since the coils simply move a little farther apart or a little closer together, depending upon whether the voltage is up or down, and the current through the secondary circuit remains constant. This is a valuable feature, particularly in the case of pole-type transformers which may be located a long distance from the power station at points where the voltage variation at different times in the day is considerable. Of course, if the transformer is loaded to the limit of its capacity,



7.—Semi-automatic station-type RV constant-current transformer.
(Courtesy of G. E. Co.)

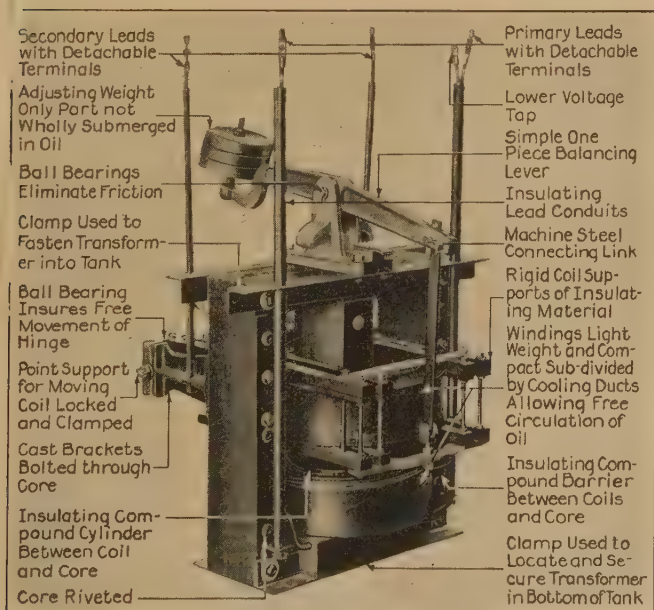


FIG. 68.—Subway-type RO constant-current transformer, with tank removed.
(Courtesy of G. E. Co.)

TABLE IX.—DATA ON CONSTANT-CURRENT TRANSFORMERS

Type of transformer	Normal kilowatt rating ¹	Primary amperes	Primary kilovolt- ampere input	Normal secondary load volts	Secondary open circuit, volts	Efficiency ²				Primary power factor ²			
						100 per cent load	75 per cent load	50 per cent load	25 per cent load	100 per cent load	75 per cent load	50 per cent load	25 per cent load
Automatic station-type RF	* 5	3.0	6.9	758	1,035	96	94	91	..	83	65	45	..
	15	9.0	20.7	2,275	3,100	96.5	94.5	91.5	..	83	65	45	..
	25	15.0	34.5	3,790	5,175	97	95	92	..	82	64	43	..
	70	42.0	96.6	10,600	14,500	98	96.5	93.5	..	81	61	40	..
Semi-automatic station-type RV	5	2.7	6.2	758	910	95	94.5	92	..	92.5	84	57	..
	15	8.0	18.5	2,275	2,725	96	95.5	94	..	92	83	56	..
	25	13.4	30.8	3,790	4,550	96.5	96	95	..	91.5	82	54.5	..
	70	37.5	86.2	10,600	12,750	97	96.5	95.5	..	91	82	54.5	..
Pole-type and subway-type RO	1	0.7	1.5	152	225	91	89	83	71	80	60	40	22
	5	3.2	7.3	757	1,050	94	92	89	80	80	60	40	22
	10	6.3	14.5	1,515	2,080	95	94	91	84	80	60	40	22
	30	18.7	43.0	4,545	6,130	96	95	93.5	88	80	60	40	22

(Data from G. E. Co.)

¹ For each type of transformer, this partial list includes the largest, the smallest, and two of the more usual sizes.² For loads of unity power factor.

TABLE X.—LAMP CAPACITIES OF CONSTANT-CURRENT TRANSFORMERS¹

Type of transformer		Number of lamps												Lamps with IL series transformers Fig. 70, C											
		Straight series lamps with film cutouts Fig. 70, A						Lamps with auto-transformers Fig. 70, B						Lamps with 1L series transformers Fig. 70, C											
		6.6 amperes						20 amperes						6.6 amperes						20 amperes					
Normal kilowatt rating ²		6.6 amperes						20 amperes						6.6 amperes						20 amperes					
		lumens	800 lumens	1,000 lumens	2,500 lumens	4,000 lumens	6,000 lumens	lumens	4,000 lumens	6,000 lumens	10,000 lumens	15,000 lumens	25,000 lumens	lumens	1,000 lumens	2,500 lumens	4,000 lumens	6,000 lumens	10,000 lumens	15,000 lumens	25,000 lumens	lumens	4,000 lumens	6,000 lumens	10,000 lumens
Automatic station-type RF	5	109	86	72	31	20	14	17	12	7	4	3	3	48	23	16	12	7	5	7	12	7	5	3	
	15	327	260	218	93	61	42	53	37	21	14	9	146	71	50	36	21	14	9	21	16	12	7	5	
	25	546	433	363	155	102	70	88	63	35	24	15	244	118	83	60	35	24	15	35	24	15	10	6	
	70	1,528	1,214	1,017	437	287	197	246	174	98	64	42	682	328	230	168	98	67	42	98	67	42	28	18	
Semi-automatic station-type RV	5	109	86	72	31	20	14	19	13	7	5	3	3	50	26	18	13	7	5	7	13	7	5	3	
	15	327	260	218	93	61	42	58	41	23	15	10	151	78	55	39	23	16	10	23	16	12	7	5	
	25	546	433	363	155	102	70	98	68	39	26	16	253	131	92	66	39	27	16	39	27	16	10	6	
	70	1,528	1,214	1,017	437	287	197	274	193	108	73	45	708	366	258	185	110	76	47	110	76	47	28	18	
Pole-type and subway-type RO	1	21	17	14	6	4	2	3	2	1	..	..	9	4	3	2	1	1	1	1	2	1	1	1	
	5	109	86	72	31	20	14	17	12	7	4	3	48	23	16	12	7	5	3	48	23	16	12	7	
	10	218	173	145	62	41	28	35	25	14	9	6	97	47	33	24	14	10	6	97	47	33	24	10	
	30	655	520	436	187	123	84	106	75	42	28	18	293	141	99	72	42	28	18	293	141	99	72	28	

(Data from G. E. Co.).

¹ Allowance has been made for line loss and for fluctuations of primary voltage and frequency.

² For each type of transformer, this partial list includes the largest, the smallest, and two of the more usual sizes.

so that the coils are together, they cannot compensate further for drops in primary voltage.

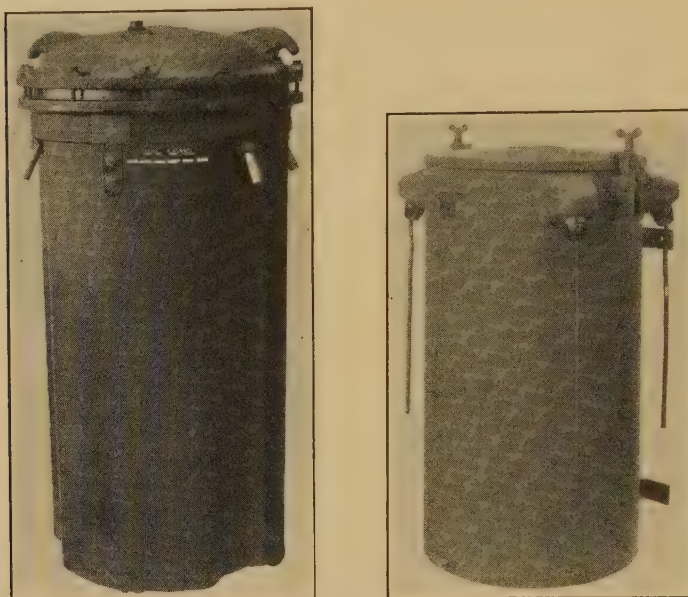


FIG. 69.—Subway-type (30 kw.) and pole-type (10 kw.) RO constant current transformers, in tanks. (Courtesy of G. E. Co.)

An even greater advantage of the constant-current transformer is that when the resistance of the secondary circuit changes due to burnout of individual lamps, the transformer maintains the current constant by movement of its coils.

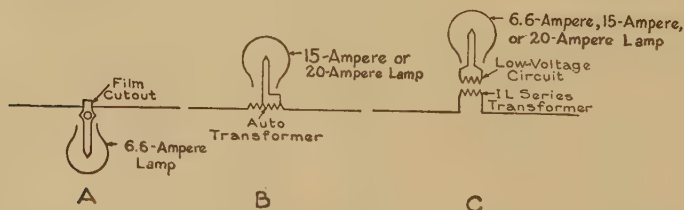


FIG. 70.—Methods of connecting lamps in series circuits, as referred to in Table X.

One ground does not affect the operation of a constant-current transformer circuit, but where two grounds occur on the same line, a considerable number of lamps may be removed from the circuit

at one time. When this happens, if it were not for the characteristics of the transformer, the voltage which was formerly distributed over the whole number of lamps—say 100—would be impressed upon those remaining in the circuit—perhaps only 12. Under these circumstances, the current through the 12 remaining would be raised to more than five times its normal value and, before the coils of the transformer could move far enough apart to protect them, the lamps would fail. In reality, however, the power factor of the constant-current transformer is never better than 92 per cent, with the result that the reactance drop is approximately 40 per cent of the total voltage on the circuit. This means that even if practically all the lamps are short circuited the current cannot rise to more than about two and one-half times normal, and that only for an instant until the coils of the transformer begin to move apart.

For practical purposes, therefore, a constant-current transformer gives almost perfect protection for a circuit. The only disturbances which are likely to cause extensive lamp failures are swinging grounds, which may give rise to “pumping” of the transformer, and lightning.

Here it should be mentioned that on a very lightly loaded constant-current transformer, it is well to provide a stop for the movable coil so that line disturbances cannot swing the coil far into the position of excessive current.

Individual lamps may be connected to a tub-transformer circuit in any one of four ways shown in Fig. 71; first, they may be inserted directly in a straight series connection; second, they may be connected to the line through an autotransformer or “compensator,” as it was once called; third, they may be connected to the line through a two-coil transformer known as an IL transformer (Fig. 72); and fourth, they may be connected in series groups through an insulating series transformer known as an SL transformer (Fig. 73).

The straight-series connection represents the simplest type of system and the one lowest in first cost. The current flowing in the line must, of course, correspond to the current rating of the lamps; hence, in this system, because of the losses of transmitting high current, the choice of lamps has usually been limited to those of not more than 10 amp. rating—6.6 amp. being the generally accepted standard. In sizes of 10,000 lumens and above, the efficiency of the 20-amp. lamps is substantially greater

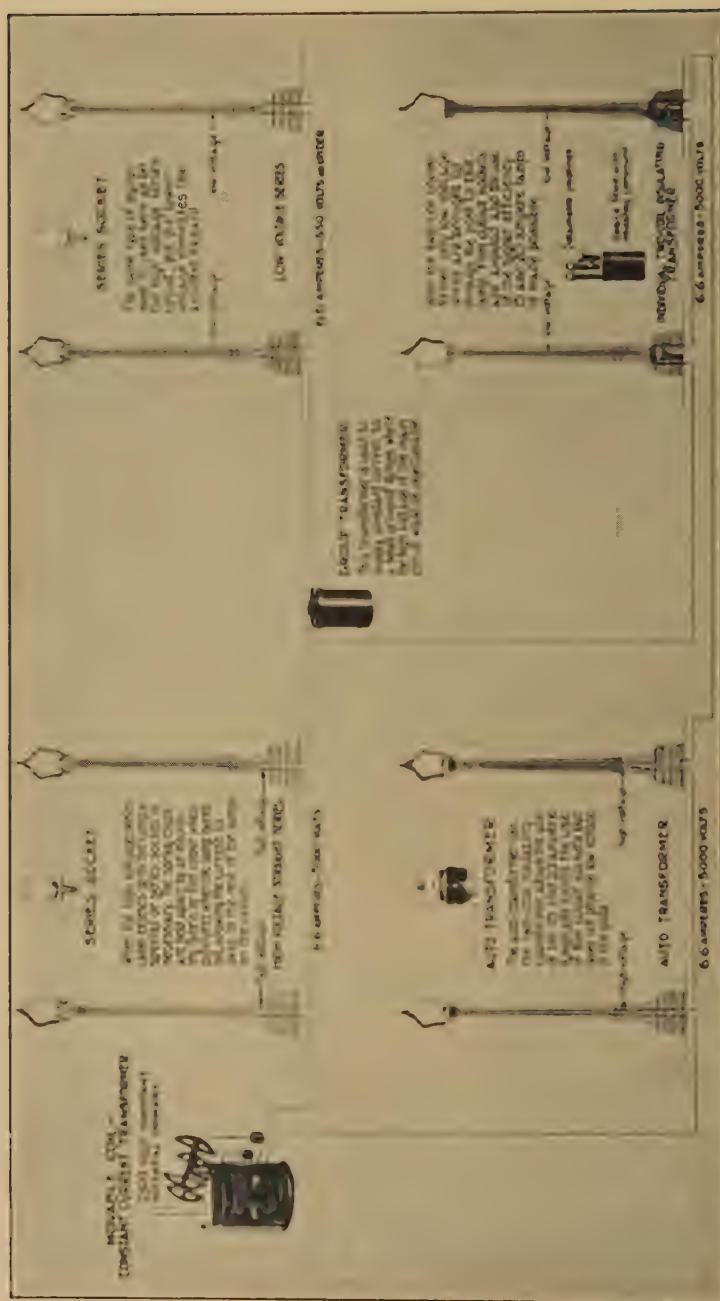


Fig. 71—An explanation and comparison of the four methods whereby individual lamps may be connected in a tub-transformer circuit.

than those of lower amperage; therefore, the straight-series circuit is not generally used for the larger lamps, with a few exceptions in the case of closely spaced ornamental systems.

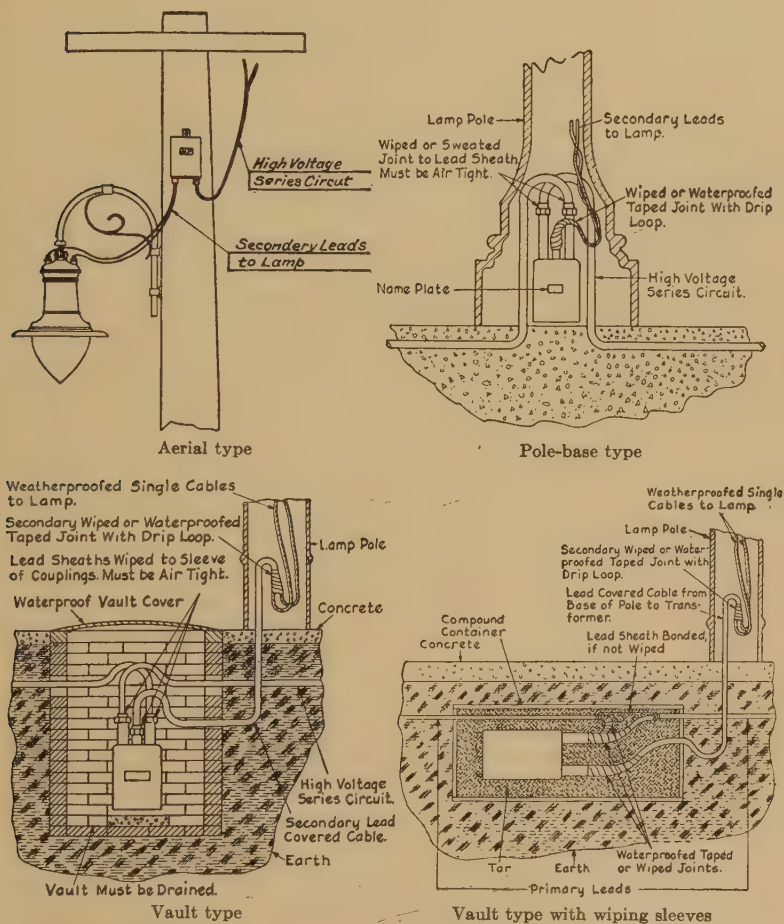


FIG. 72.—Methods of mounting II. series transformers. Data in Table XI.

Both autotransformers and two-coil transformers are used to step up the line current from the usual value of 6.6 to 15 or 20 amp. and thereby to permit the use of the more efficient lamps. They also have a substantial advantage in that the primary circuit is not open when a lamp burns out, and so the necessity for

film cutouts is eliminated. The autotransformer has a slightly lower first cost than the two-coil transformer. On the other hand, since the autotransformer is wound in a single coil, it does not insulate the lamp from the high-voltage line. In the case of overhead systems, two-coil transformers are usually located on the cross-arm of the pole and are cut into the circuit at this point, while in underground systems they are located in the base of the

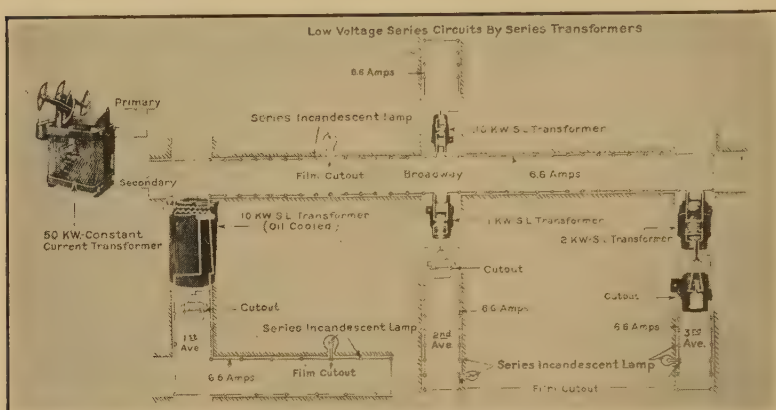


FIG. 73.—Pictorial diagram of low-voltage series circuits supplied by SL series transformers. See Table XII for data on lamp capacities. (Courtesy of G. E. Co.)

standard or in a nearby manhole. Autotransformers, because they have no insulating value, are customarily combined with the lighting fixture. Experience has shown that a great majority, perhaps three-fourths, of all troubles with overhead series circuits occur in the loops which connect the lamps to the main circuit on the pole; when two-coil transformers are used, grounds in the loops produce no effect whatever, and an open circuit in the loop simply cuts this one unit out of service.

Instead of connecting just one lamp to the secondary of a two-coil transformer, a group of lamps in series may be so connected. In this case the transformers are usually of one-to-one current ratio, with a secondary voltage of approximately 500 volts, to insulate the group of lamps from the high-tension series circuit. This plan usually finds its application in connection with underground circuits in residence districts and parks, where the comparatively low voltage on individual loops greatly reduces the cost of cable insulation. A group transformer to operate only

TABLE XI.—DATA ON TYPE IL SINGLE-LIGHT SERIES TRANSFORMERS¹

Lamp rating		Open-circuit effective voltage	Approximate efficiency, per cent	Approximate power factor, per cent
Lumens	Amperes			
1,000/ 2,500	6.6	102	92	98
2,500/ 4,000 ²	6.6/15 ²	164	93	98
4,000/ 6,000 ²	15/20 ²	110	94	98
6,000/10,000	20	117	95	98
10,000/15,000	20	184	96	98.5
15,000/25,000	20	208	96	98.5

(Data from G. E. Co.)

¹ A transformer of this type is used for operating a single series lamp of 6.6, 15, or 20 amp. on a 6.6-amp. constant-current circuit.

² These transformers have two sets of secondary leads, supplying the lower current for the smaller lamp and the higher current for the larger lamp.

TABLE XII.—LAMP CAPACITIES OF SL SERIES TRANSFORMERS¹

Size of trans- former in kw.	600- lumen lamps	800- lumen lamps	1,000- lumen lamps	2,500- lumen lamps	4,000- lumen lamps	6,000- lumen lamps
0.25	5	4				
0.5	11	9	7	3		
1.0	22	17	14	6	4	
2.0	43	34	29	12	8	5
3.0	65	52	43	18	12	8
4.0	87	69	58	25	16	11
5.0	109	86	72	31	20	14
7.5	164	130	109	46	30	21
10.0	218	173	145	62	41	28

¹ The figures in this table apply to 6.6-ampere lamps with film cutouts. For transformers of 1 kw. and over an allowance of 5 per cent for line loss is included.

two or three lamps is, in general, unsatisfactory, since upon the failure of one lamp there is not enough voltage imposed upon its film cutout to cause it to puncture and close the circuit.

Another plan which has been tried to keep down the voltage of series circuits is to operate the tub transformers at 20 amp. Under these conditions, the high-candlepower 20-amp. lamps are connected directly to the circuit and film cutouts are required. The low-candlepower 6.6-amp. lamps are operated on 20- to 6.6-amp. transformers.

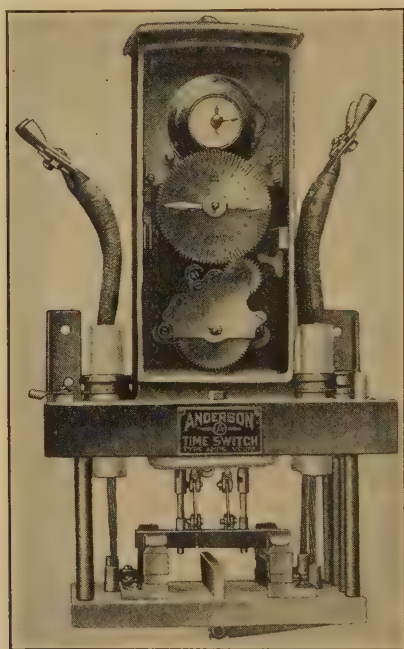


FIG. 74.—Anderson hand-wound time switch of the high-potential type, with oil tank removed. (Courtesy of G. E. Co.)

Until quite recently, constant-current transformers were housed in substations and required the services of an attendant to lock the regulator coils apart and then bring them together carefully after the power was turned on, thus preventing an initial rush of current through the lamps. As street-lighting systems have been extended, particularly in the larger cities, the number of series lines running to the substation has multiplied to an almost prohibitive extent. Furthermore, the cost was often

excessive in that many circuits ran out as much as 5 miles from a station before the first lamp to be served by that particular circuit was reached

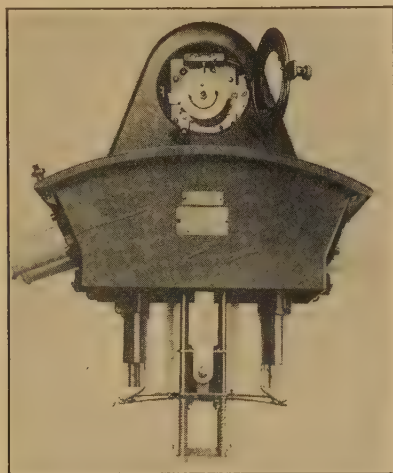


FIG. 75.—Sauter electric-wound time switch, with oil tank removed. (*Courtesy of G. E. Co.*)

CONTROL OF SERIES CIRCUITS

To overcome these limitations of the station-type transformers, the so-called "pole-type" regulator has been developed. This is simply a movable coil constant-current transformer mounted in a weatherproof case, with sufficient reactance so that the transformer may be started with the coils together without danger of injury to the lamps. A number of these pole-type transformers may be connected to a special 2,300-volt feeder running back to the substation or they may be connected individually to the adjacent 2,300-volt distribution system. In the latter case, special provision must be made for turning the circuits on and off. Time clocks (Figs. 74 and 75) connected to oil switches at the transformers are frequently employed, or a pilot wire running back to the station may be used to energize a number of oil switches (Figs. 76 and 77). Another method is the cascade system in which the oil switch for one transformer is connected into the circuit of the preceding transformer (Fig. 78). Cascading should not be carried to such an extreme, however, that, if

the first circuit fails, a considerable portion of the city will be left in darkness. A widely used form of cascade control is that

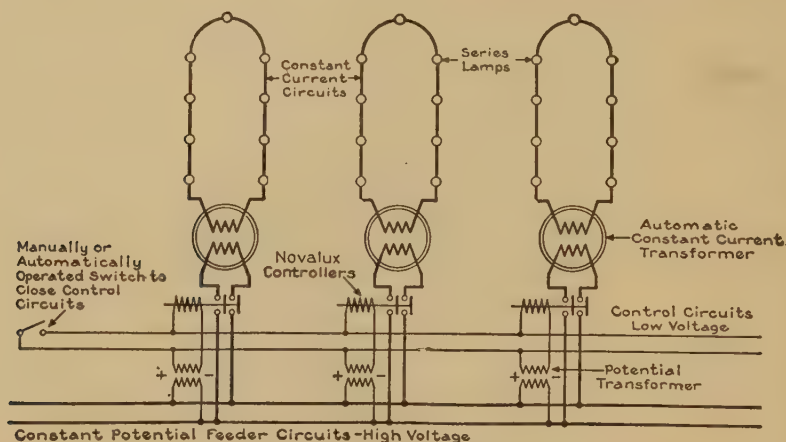


FIG. 76.—Pilot wire control system in which RO transformer circuits are turned on and off by multiple controllers operated through a low-voltage control circuit.

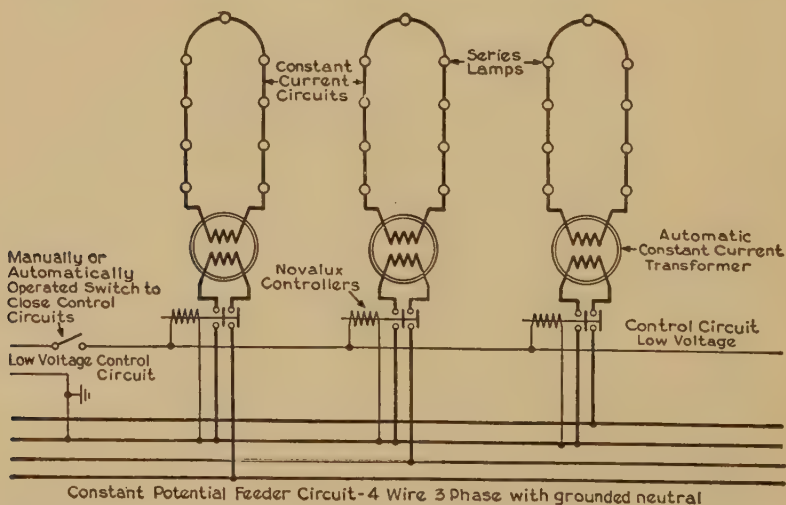


FIG. 77.—Another form of pilot-wire control system, in which the feeder circuit is four-wire three-phase with grounded neutral.

in which a series lighting circuit contains several series controllers, each of which controls an RO transformer circuit (Fig. 79).

Recently, oil switches have been operated from the 2,300-volt line without the use of any additional wires, the method of

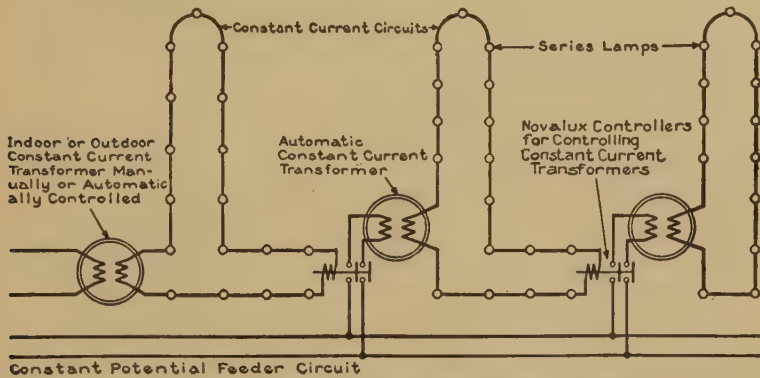


FIG. 78.—Cascade control system, in which each circuit contains a series controller which turns on and off the next circuit.

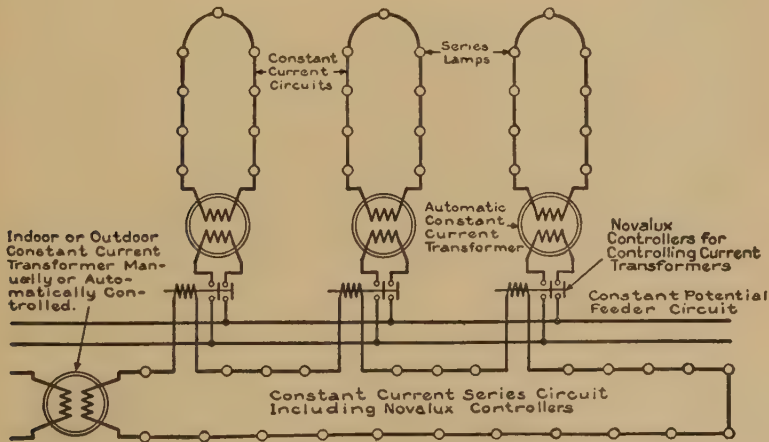


FIG. 79.—Series-control system, in which several RO transformer circuits are turned on and off by series controllers placed in a series lighting circuit which acts as the control circuit.

operating the switch being by the use of high-frequency “carrier current” superimposed upon the 2,300-volt network. It is probable that, in the future, this method of operation will find extensive application.

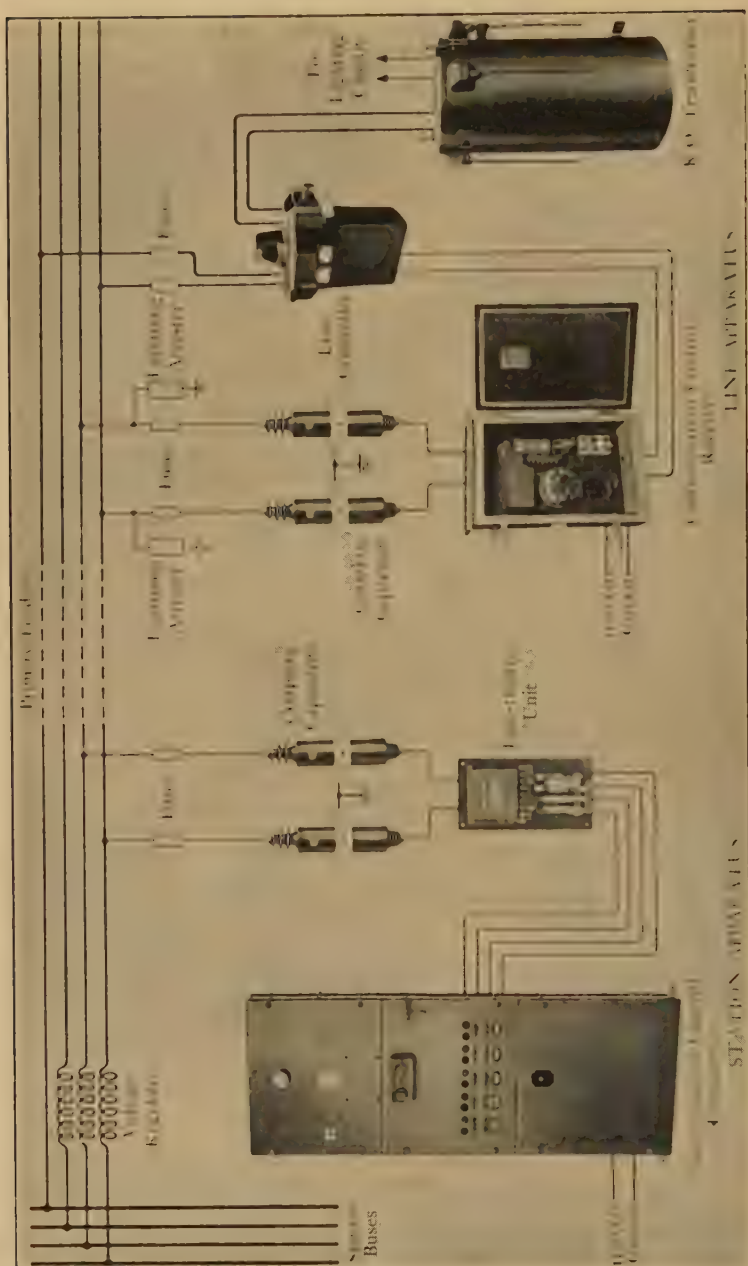


Fig. 80.—Pictorial wiring diagram of the carrier-current control system. (Courtesy of G. E. Co.)

Automatic Series-reactance Circuits.—In the automatic series-reactance circuits, an automatic current-control device known as the “Wood regulator” is used instead of the tub transformer. This regulator consists of a single coil, in series with the lamps, having a counterweighted moving core to vary the reactance. It is commonly insulated from the main 2,300-volt supply by a constant-potential transformer. Where this is done and the regulator is designed to control the current from zero to full load, the characteristics of this circuit are practically identical with those of the constant-current transformer circuit, and the operating results are similar and satisfactory.

Constant-potential Series Systems.—To avoid the investment required for a constant-current transformer installation, groups of 100 or more series lamps have often been connected directly across the 2,300-volt multiple supply, sometimes even without an insulating transformer. If, for example, 1,000-lumen, 6.6-amp. lamps rated at 9.8 volts each were to be employed, 235 of them would be required in series to add up to 2,300 volts. No serious consequence would follow the burning out of one lamp on such a circuit, for the voltage on the others would be increased only about one-half of 1 per cent. On the other hand, the burnout of a considerable number of lamps in one night would cause a substantial increase in current through those remaining, and a short circuit of part of the line would be almost certain to burn out all of the lamps remaining. Another serious practical disadvantage of this system is the probability of losing count of the exact number of sockets added to or subtracted from the circuit from time to time with a resultant continuous overburning or underburning of all the lamps in service.

Stationary Reactance Regulators.—Much ingenuity has been displayed in attempts to overcome the inherent disadvantages of the constant-potential-series system just described. Usually the circuit has been insulated from the general distribution system by means of 2,300-volt transformers having a relatively high reactance. Insulating the circuit in this way tended to cut down the number of short circuits, and the high reactance of the transformer served to protect the remaining lamps to some degree when part of the circuit was shorted. Some manufacturers went further and, instead of a film cutout, provided a small choke coil to be placed in multiple with each series lamp. When a lamp burned out, the full amperage of the line was forced through its

auxiliary coil which normally passed but a negligible current. The full current through the coil induced a reactance voltage three to four times that of the lamp itself, so that after a number of lamps were burned out the current in the circuit was actually lower than under normal conditions.

Where an ammeter is provided to record the actual current in the secondary circuit, and where the constant-potential transformer has taps which make it convenient for an attendant to bring the current back to its normal value in case of change, relatively satisfactory operation is obtainable from this type of circuit. As a further refinement, two-coil transformers may be substituted for the choke coils and in this way the lamps themselves are effectively insulated from the high-tension circuit.

The power factor of all of these combination circuits is lower than that of the constant-current transformer circuit if the lamps are sufficiently protected against burnouts when part of the line is shorted. Also, the more elaborate the installation, the more nearly it approaches in cost the constant-current transformer system, and from the standpoint of operation over a period of years, the latter is always to be preferred.

Almost any non-standard system will operate satisfactorily when directly under the control of its designer who has a personal interest in the success of the plan he has developed. It is a matter of record that such systems, however, after passing into the hands of others, have been the source of the majority of the complaints regarding the operation of series circuits and lamps.

CHAPTER IX

MULTIPLE SYSTEMS AND THEIR CONTROL

As stated in the preceding chapter, the principal reasons for the widespread adoption of series circuits for street lighting were the general use of arc lamps, the frequent absence of multiple distribution, and the convenience of control. Multiple distribution for street lighting, however, has long been employed in a few

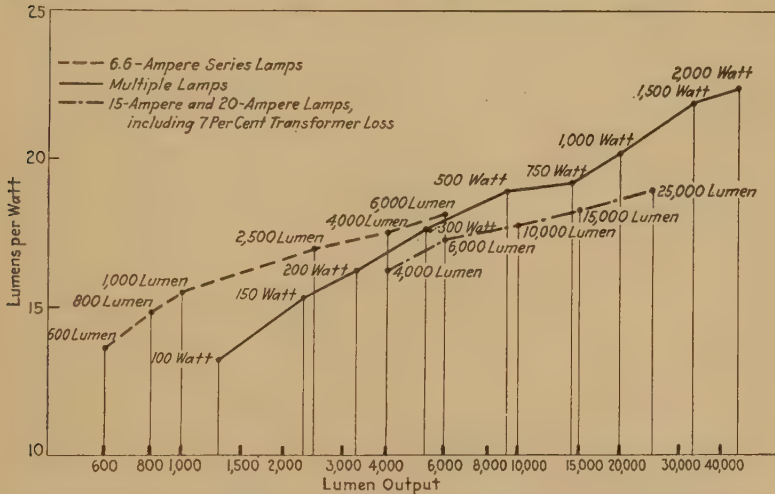


FIG. 81.—Relation between lumen output and lumens per watt for lamps of the types and sizes commonly employed in street lighting.

cities, and now the feasibility of this system for general use is receiving more and more study from the entire central station industry.

The proponents of the series-distribution system call attention to the following points:

1. In the smaller sizes, the series incandescent lamps are more efficient than the multiple lamps, as shown in Fig. 81; in all sizes, lamps operated on constant-current circuits have a somewhat better candlepower maintenance.

2. The rated life of the series lamp is about one-third longer.

3. The series lamps in the smaller sizes are more rugged than the multiple.

4. The filament in the series lamp approximates more closely a point light source and therefore the light may be controlled more accurately.

5. Since the series lamps are rated in lumen output, this allows contracts with cities to be made on a fixed output basis.

6. A properly installed series circuit affords freedom from voltage variations and voltage drop.

The following advantages are advanced by the proponents of multiple distribution as reasons why all street lighting will some day be fed by multiple circuits:

1. In the larger sizes the multiple lamps are slightly more efficient than even the high-current series lamps. A greater differential in favor of the multiple lamps is shown when the series lamps are charged with a loss of about 7 per cent occurring in their individual transformers.

2. The flexibility of the multiple distribution permits the easy addition of more lamps or the substitution of larger lamps.

3. The transforming equipment and fixtures are simpler and lower in cost.

4. There is pressing need for central station space now occupied by special transformers and for ducts now filled with series cables.

5. A duplicate distribution system is eliminated.

6. The load factor of existing multiple circuits is improved.

7. Multiple lamps are less expensive to manufacture and, therefore, are lower in cost.

8. The possibility of wholesale burning out of lamps is eliminated.

In European cities, multiple street-lighting systems are practically as common for both arc and incandescent lamps as are series systems in this country. Even here, where series circuits predominate, there are a large number of multiple systems in operation. Of cities so supplied, New York is the most prominent example, with many thousands of such lamps. It is worthy of note, however, that in cities nominally lighted from series circuits, considerable numbers of street lamps will be found operated from the multiple-distribution systems.

The matter of flexibility is of immediate importance in the problem of designing street lighting for American cities and

towns. There is not only steady growth in population and area covered, but there are also unexpected demands from time to time for increased street-lighting service in given areas. The result, with series circuits of 100 to 200 lamps included on a single line, is that there must be an almost continual process of rearrangement and redivision of lamps among different circuits. In many cases, service can only be provided after considerable delay and at relatively high cost, because existing circuits are so completely loaded that the addition of a few lamps makes necessary an extended revision of the system. No such limitations attend when the street lamps are operated from the general multiple-distribution system.

An additional advantage of multiple street lighting is that the multiple circuit is now used exclusively by central stations for every other service. Were it used generally in street lighting as well, the reduction in types of apparatus required and the resulting simplicity of operation would benefit both the electrical manufacturer and the central station.

At the present time, when a new real-estate subdivision or allotment is opened, it is common practice for the lighting company to run a set of 2,300-volt feeders to cover the plot, and to furnish service to houses as they are built. At the same time, a series-transmission line is extended and in some cases a separate pole-type series transformer is installed to furnish the necessary street lighting for the subdivision. Furthermore, in anticipation of increased requirements for service, both supply circuits are installed with a large excess capacity. Duplication of service is, of course, expensive and tends to retard the development of adequate street lighting. In view of the fact that the distribution systems to residential districts almost always have excess capacity, it is significant that a street lamp of only the 200-watt (3,200-lumen) size has about one-quarter the demand and double the energy consumption of the average residence customer.

There is an insistent demand for the extension of electric street-lighting service in territory not now served by series lines, as in Ohio cities, where in the past a considerable portion of the lighting has been furnished by natural gas, the supply of which is being rapidly depleted. In such territory, the residences are, for the most part, furnished with current from overhead circuits along the rear lot lines, and the introduction of a pole line along the street to carry the series circuit has often met with a decided

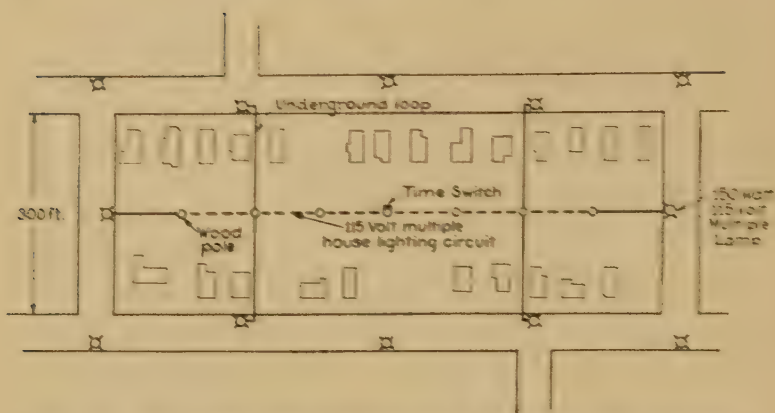


FIG. S2.—Low-tension multiple distribution for residence street lighting.

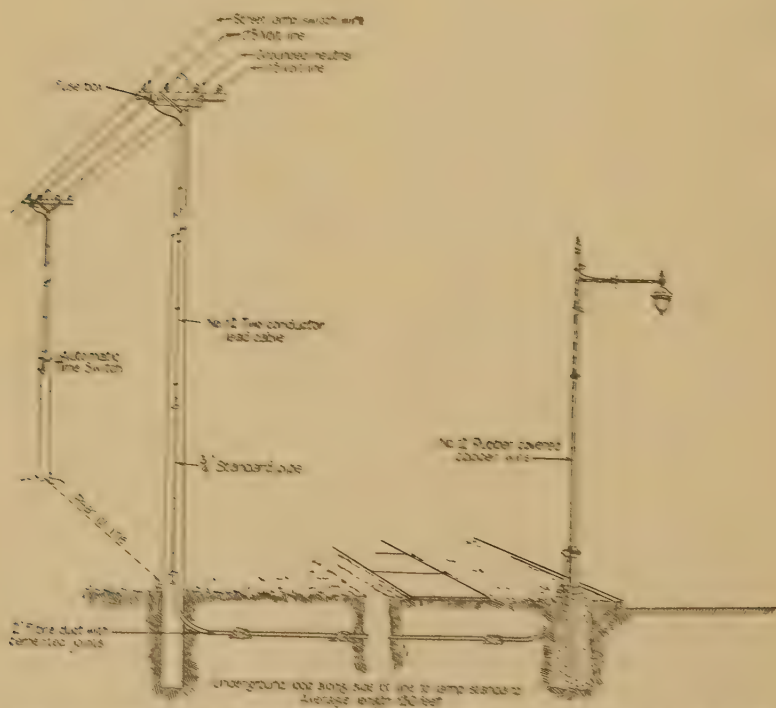


FIG. S3.—Details of the low-tension multiple distribution sketched in Fig. S2.

protest from the property holders. On the other hand, the cost of underground construction, with ducts running parallel to the curb, is very high, especially in view of the increasing frequency with which concrete driveways now cross the tree lawn in residence districts. High-tension underground lines passing through private property from the rear lot lines to the street also involve expensive construction if safety is to be assured. Taken altogether, the conditions point toward the use of low-tension multiple circuits from the pole lines in the rear to the posts on the street, brought out either overhead or underground, as occasion may require. An installation of this type is sketched in Figs. 82 and 83. Under these circumstances the underground construction may be in the form of a lightly insulated sheathed conductor. Such a conductor is very much less expensive than that designed for high-tension work, and it can often be installed without digging a deep trench across the lawn. If such a conductor is accidentally severed no serious harm can result, and the loss in itself is small.

With respect to both the series and the multiple lamps, it should be emphasized that series lamps are designed for operation on series circuits and multiple lamps are designed for operation on multiple circuits. Some have tried out series lamps operated from autotransformers with a 115-volt primary and series-lamp voltage secondary, thinking to combine the longer life and somewhat better maintained output of the series lamps with the advantages of the multiple distribution. Such a hybrid arrangement does not give a satisfactory operating condition for the following reasons:

1. **Variation in Voltage of Individual Series Lamps.**—As series lamps are designed for constant current the unavoidable variations of manufacture are made to appear as variations in the voltage rather than in the current. Depending on the extent of variation, individual lamp life and output may be seriously affected.

2. **Future Changes in Efficiency.**—Series lamps are rated in lumens at various amperages and improvements in efficiency mean corresponding changes in lamp voltage.

3. **Simplified Construction.**—The elimination of the individual autotransformers and the use of 115-volt lamps result in a simplified construction, higher power factor, and a lower first cost.

4. **Lamp Efficiency.**—Series lamps are rated at a higher efficiency than multiple lamps, but this difference is reversed when the transformer loss is considered. Furthermore, series lamps give a poor candlepower maintenance when burned on constant voltage instead of constant current. On the basis of average lumens throughout life, multiple lamps on multiple circuits are more efficient. For example, the 115-volt 500-watt lamp (9,400 lumens initial) gives a higher mean lumen output throughout life than does the 10,000-lumen 20-amp. lamp burned on a multiple circuit even though with the latter, with its autotransformer, consumes about 550 watts.

5. **Operating Cost.**—An analysis of costs shows that multiple lamps can be operated more economically for equivalent light output than can the series lamps on multiple circuits. This is because of the elimination of the autotransformers, the better sustained lumen output, and the fact that even though the life of the multiple lamp is shorter it has a materially lower first cost.

6. **Failure to Supply Rated Lumens.**—Possibly the most serious consideration entering into the use of series lamps on multiple circuits is the failure of individual lamps in service to supply even approximately the rated lumens on which the contract is made.

CONTROL OF MULTIPLE CIRCUITS

Today if incandescent street lamps were to be operated throughout the 24 hr. instead of at night only, there would be no discussion as to the desirability of connecting them to the existing multiple-distribution system, but the obvious difficulty in this practice lies in obtaining a thoroughly satisfactory method for turning the lamps on and off. Of course, wherever the load is sufficiently concentrated to justify a separate circuit from the substation, as in the case of many "white-way" installations in the business streets of cities, the lamps may be switched at the substation in the same way as in the case of series circuits. Usually, however, to bring the circuits back to the substation entails a prohibitive expense in copper and it is necessary to supply the lamps from feeders located nearer the lamps. In this case, the simplest plan of control is to have the lamps turned on and off by hand. Where labor is cheap, as in some of the European and Asiatic countries, this has been found a satisfactory and economical solution. In this country, there are some cities

where the "white-way" lighting is turned on and off by the policemen on duty. In view of the higher cost of labor, however, in the United States and the extended distances between lamps, hand control is less desirable. Furthermore, the difficulties which the gas companies have experienced in obtaining thoroughly reliable operators except at very high prices, have served to deter electric-lighting companies from resorting to this plan.

Most of the efforts toward the development of remote control of multiple street lamps can be grouped under four general heads: cascading, pilot control, time switches, and carrier current.

Cascade Control.—The cascade method of control (Fig. 84) has been applied where separate multiple circuits have been run for groups of street lamps, as in the case of some "white-way" installations. In this method, the lamps in the section nearest

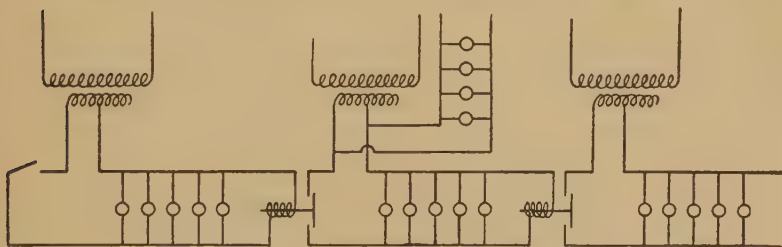


FIG. 84.—Cascade control of multiple street lamps.

the substation or control point are generally switched on and off by hand. Energizing of this section serves to close a relay operating the switch which connects the second section to the most convenient 115-volt supply. At the end of the second section is a similar relay which, being energized, closes the circuit for the third section of lamps, and so on. Opening the switch on the first section of lamps serves to deenergize the other sections of lamps in the same order. It is obvious that a method of this kind can be used for either alternating-current or direct-current systems, or even a combination, and the load may be carried from as many separate transformers or sets of feeders as desired.

In the cascade system, a failure of current supply in any section will turn out the lamps in succeeding sections of that cascade. This difficulty, however, can be minimized by provision for hand operation of the switches in case of failure of one of the units.

In addition to the straight cascading of multiple circuits, it is sometimes found desirable to control a group of multiple lamps

from an existing series circuit. The principal application is for bridges, elevated railway structures, safety zones, and other locations where it is desired to use only low-voltage circuits.

Pilot-wire Control.—In the pilot-wire method of control, as will be seen from Fig. 85, lamps of the system are grouped in sections of suitable size to be controlled by a single switch and the separate switches are operated from a pilot wire which is energized from the substation. The pilot wire can obviously be of low current-carrying capacity—steel wire may be used if desired—since it does not carry the lamp current but simply serves to energize the switch relays.

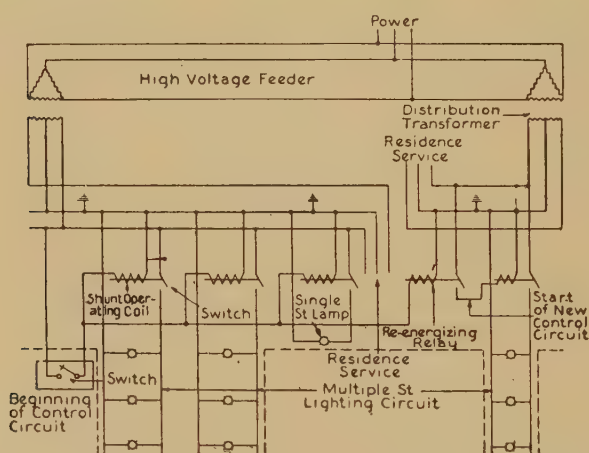


FIG. 85.—Multiple pilot-wire control of multiple street lamps.

Most pilot-wire systems require the use of current in the pilot wire for 12 out of the 24 hours. The switches should preferably be in the closed position—that is, the lamps should be lighted—when there is no current flowing in the control circuit. This insures that even if the pilot circuit is accidentally broken the lamps will all be lighted.

For this service several types of relays have been developed, some of which, termed “mercury switches,” employ mercury for one or both contacts. In most cases pilot-wire systems use grounded returns, thereby saving half the run. Also, when desired, pilot circuits can be cascaded, the power for the second pilot circuit being obtained from a convenient 115-volt supply.

Pilot wires may connect the control switches in series, but the multiple connection is usually preferable; with the multiple control there is a greater flexibility as regards extensions, and open circuits in the pilot wire will not, in general, affect as large an area.

Another type of pilot-wire switch is one which is operated by current impulses rather than by a continuous flow of current. With this device, the first time the control wire is energized the lamps are lighted. The next time the lamps are turned off, and so on. With this form of control, there exists a possibility of lamps being left turned off when it was desired to have them on, or *vice versa*, due to the switches getting out of step. Hand setting should be provided for individual switches which may drop out of step.

Experiments have indicated the practicability of switches operated from impulses of different strength over pilot wire. In one such mechanism, the solenoid has two plungers so adjusted that a certain current will lift one and close the circuit. Passing double the current through the control circuit lifts the second plunger, which releases the first plunger and opens the circuit. Such an arrangement using different impulses for the "on" and "off" positions has the advantage of avoiding the possibility of switches falling out of step.

Time Switches.—One of the first devices for turning lamps on and off was the clock or time switch. Early designs were often unreliable in operation and, therefore, quite unsatisfactory; however, there are available at present, time switches which withstand the severe conditions to which they are subjected. Wherever possible, the time switch is located so that it controls several lamps.

Time switches may be had which are electrically wound. Some of them, called astronomical switches, have been designed to vary the time of switching the lamps according to the time of year.

A tiny synchronous motor-operated clock switch, requiring an almost negligible wattage, is also available for remote-control switching on alternating-current circuits. This switch necessarily finds application only in systems whose average frequency is well maintained and where there are but few interruptions of service. Otherwise, the switches are liable to require a considerable amount of resetting.

Experience has indicated that clocks require frequent attention and regulation to keep them operating and in close agreement with each other. This factor, together with the question of initial cost, has hindered the more extended use of these devices.

Carrier Current.—Quite a different and a more promising solution of the problem of providing an economical and satisfactory remote control for multiple street lamps appears to lie in the development of a system of switch controls operated without pilot wires and without clock mechanisms, but so arranged as to be actuated at will from the power station or control point.

1. One possibility is the operation of a remote control switch by "winking," or quickly opening and closing the supply circuit. Provided that the other load carried on the same distribution system is of such character that a momentary interruption of power is not objectionable and does not interfere with its operation, this method will work out successfully.

2. Experimental apparatus has been built showing the possibility of operating switch relays by varying the frequency of the alternating-current supply a few cycles above and below normal. An arrangement of this kind might be practical, at least in smaller communities where there are no serious difficulties attendant upon momentarily changing the speed of the generators. On large interconnected systems it does not appear feasible.

3. Operation of the switch relays by means of selenium or photo-electric cells has been suggested. The operation of such switches would be entirely dependent on the amount of daylight, and would not control the lamps according to the burning hours fixed more or less arbitrarily in many street-lighting contracts. Of course, it would not be possible to turn the lamps on and off for test or other purposes, except by the additional provision of hand-operated switches.

4. The use of carrier current for the operation of relays is receiving much attention. Detailed preliminary experiments indicate the practicability of utilizing a high-frequency transmission over the existing distribution system. No other field of experiment seems to offer such probability of success in the automatic control of street lamps.

It is evident that any system thus operating over existing circuits must be positive in operation; it must not involve a high cost per unit installed; it must not require the addition of any considerable amount of equipment on the 2,300-volt lines;

its mode of operation, particularly if it involves the use of high frequency, must be such that there is no objectionable or continuous telephonic or radio interference; and it must cause no injury to transformer insulation or to any apparatus forming a part of the present standard distribution system.

At the present time this system has been developed to a point where groups of lamps are being controlled by carrier current. Thus far, however, the cost of the receiving apparatus and the difficulty of getting the impulses onto the secondary network have prevented the adoption of this system of control for individual multiple lamps.

CHAPTER X

FACTORS AFFECTING VISIBILITY ON THE STREET

In a street-lighting installation, the more powerful the light sources the more illumination there is upon the street and, from that standpoint alone, the easier it is to see. If the glare is increased at the same time the illumination is increased, however, this tends to detract from the benefits of the higher illumination. A full evaluation of street lighting must take account of several factors, some of which assist vision and some of which hinder it.

Among street-lighting engineers there are many divisions of opinion as to what constitutes the proper basis of measuring the positive factors in street illumination. Some hold that the foot-candle reading at the point of minimum illumination on the street—usually found about midway between lamps—is the proper measure of the effectiveness of a system. Another group maintains that the average horizontal foot-candles over the entire street—measured either between curb lines or property lines—is a fair evaluation. A third group stresses average foot-candles measured on a vertical plane. A fourth group looks upon the average brightness of the pavement, measured in the less familiar terms of foot-lamberts or milli-lamberts, as the proper criterion. Still others are satisfied merely to set down the amount of light supplied to the street in terms of generated lumens per linear foot of street.

At first thought, it would appear that since average horizontal illumination is the almost universal basis for comparison of interior lighting systems, it should also be the logical basis in the case of street illumination. The reader is reminded, however, that in Chap. II it is emphasized that ordinary principles of vision in interior lighting—such as color discrimination and judgment of three dimensions—must in large measure be laid aside when dealing with the very meager levels of illumination employed in the average street-lighting installation. Except in the best installations, it is possible to depend only slightly upon direct illumination of the objects on the street. Con-

sequently, before a conclusion can be reached as to the fairest method of evaluating the positive factors, it is necessary to study in detail the means by which we see on the street at night.

Four such methods of vision are recognized:

1. By reflected light or, as it ordinarily is termed, "direct illumination."
2. By silhouette.

vision by reflected light is, which is most familiar to the



objects in the foreground are seen from them to the eye.

on the object and is reflected there is a sufficient amount of light. Ordinarily is in daylight and reveals the object in its true colors. Street illumination sufficient for direct illumination will be sufficient in the future, with the present amount of light on the street to see by day in business districts or in the

immediate vicinity of a lamp in the outlying districts. It is important to note that an object is not revealed by the amount of light falling *on* it but rather by the light reflected *from* it, and that, providing all other factors are kept constant, an object

which is so nearly black as to have a reflection factor of only 10 per cent would require for the same visibility five times as much light as a similar object of such a color as to have a reflection factor of 50 per cent.

Vision by Silhouette.—Vision by silhouette is a factor of the utmost importance in street lighting, particularly in regard to illumination of the roadway as distinguished from the sidewalks. Millar, in 1910, was the first to emphasize its importance. In silhouette vision, the object is distinguished not because of its particular color or detail, but because of contrast with its immediate background; it is usually seen as a dark outline or projection against a lighter background. Even in daylight most people depend upon silhouette vision to a far greater extent than they realize. For example, on the highway a distant automobile is more often than not first recognized as a dark outline against the horizon or against the light-colored road surface.

The similarities and the differences between conditions for good vision by direct illumination and by silhouette may perhaps be better understood by visualizing a street illuminated in two radically different ways.

First, assume a concrete road surface almost white or at least light gray in color. Illuminate this roadway by means of light rays falling perpendicularly upon it, as from a great number of small concentrating projectors placed directly above the road and pointed straight down upon it. Under these conditions, it would be said that the horizontal illumination of the street was good and, as a matter of fact, the street surface would appear markedly bright. On the other hand, a man standing on the street would be very poorly illuminated, for the directly downward light from the projectors would illuminate brightly the top of his hat and shoulders, but would otherwise leave him in comparative darkness. We might even be unable to tell at a little distance whether the man's back or his face was toward us. Vision by direct illumination would be poor, but there would be little danger of failing to recognize that the man was there, for he would stand out in bold silhouette against the relatively bright background of the pavement.

Second, suppose that instead of having the light coming directly down on the street, the projectors were placed at intervals right at the pavement level and the light rays directed

both up and down the street at a grazing angle. Under these circumstances the road surface if non-specular would not be nearly as bright. On the other hand, because of the high vertical illumination, it would be easy to see the pedestrian by direct illumination, even at a considerable distance, to distinguish his white collar, and to tell something about his features. Yet by silhouette alone he would not be at all conspicuous unless he wore such a light-colored suit that he actually appeared as a light object against the darker background of the pavement.

Third, with the projectors at this grazing angle, assume that instead of a concrete pavement, a black asphalt polished by automobile traffic were so illuminated. Although the surface itself might be black, nevertheless, because of its sheen or polish, it would give an almost mirror-like reflection of the light sources which would take the form of paths or wakes of brightness extending all along the pavement from the light sources to the eye. If enough projectors were present, the sheen might cover the whole surface of the pavement, much as the sun seems to do when one drives directly westward just at sunset on a summer afternoon. The pedestrian on the street would receive just as much direct illumination as before but, in addition to this he would be very well silhouetted, for the wakes of light would be interrupted by the outline of his body.

Fourth, with the asphalt pavement, return the projectors to their original positions directly above the street. As in the first case, the pedestrian would be very difficult to distinguish by direct illumination and, furthermore, since the specular reflection from the pavement would be returned directly upward, the road surface itself would appear exceedingly black, and the results would be practically as unsatisfactory as though the roadway had a dull black surface absorbing nearly all of the light. It would be almost impossible to distinguish the pedestrian either by direct vision or by silhouette. This is why it is so hard on a rainy night to distinguish a traffic policeman standing at the intersection of two thoroughfares paved with asphalt, even though there is a comparatively strong light directly over his head.

These conditions may be summarized as follows:

1. Vertical rays on a light-colored pavement result in poor conditions for vision by direct illumination and in excellent conditions for vision by silhouette.

2. Very oblique or horizontal rays on a light-colored pavement result in good conditions for vision by direct illumination and only fair or even poor vision by silhouette.

3. Horizontal rays on a dark-colored pavement result in good conditions for vision by direct illumination and, if the pavement is specular, good vision by silhouette.

4. Vertical rays on a dark-colored pavement, or particularly on a wet pavement, result in poor conditions for vision both by direct illumination and by silhouette. There is no condition of lighting which will produce good vision by silhouette on a dull black surface such as oil-bound macadam.



FIG. 87.—Vision by silhouette—the objects seen in Fig. 86 by direct illumination are now seen largely as dark silhouettes against the bright spot on the pavement. Vision by shadow is also in evidence.

As has been suggested, the usual requisite in silhouette vision is that the background be brighter than the object. Fig. 87 shows that the bright spots of light under the street lamps afford a convenient means of silhouette when the object is tall, even if it is at a considerable distance from the lighted area. These bright spots are very marked in the case of comparatively light-colored diffusely reflecting pavements such as new concrete.

With asphalt or brick, the pavement soon acquires a polish from the action of the tires and the oil from the engine exhausts. On streets in this condition, or on any paved street that is wet, the bright spots beneath the street lamps tend to disappear and the light rays are specularly reflected by the surface, forming

paths or wakes of brightness over the pavement extending all the way from the lamps to the eye. From the nature of this effect, it is not possible to develop a sheen covering the entire pavement from a single row of lamps, even if they are located in the center of the street. However, with a system having lamps on both sides of the street, spaced not too widely, the wakes of light from the lamps merge into one broad strip giving a sheen of brightness over practically the entire pavement and producing thereby a bright background against which objects may be seen in their true outline with sufficient distinctness so that an automobile driver is enabled to locate them accurately and, if they are moving, to determine their direction of travel and estimate their rate of speed.

Too much emphasis cannot be given to the importance of pavement brightness in visibility on thoroughfares and residence streets. On white diffusing pavements such as new concrete, brightness varies practically in the same proportion as the foot-candles measured on the horizontal. On specularly reflecting pavements, although the average brightness in the direction of the eye may be lower, still there is a redeeming feature in that the uniformity of brightness is better and the pavement areas midway between lamps look brighter. This is possibly the reason why some have even said that the black, glossy pavements are easier to light than white concrete. Night photographs tend to substantiate this claim, in that the glossy pavements with a uniform sheen of brightness stand out particularly well, while the photographs of the white diffusing pavements emphasize the comparatively light and dark places. The authors do not concur entirely with these conclusions, since on a concrete pavement the very bright spots beneath the lamps, which are not present with the glossy pavement, are of material assistance in discerning by silhouette. Unquestionably, however, a black, glossy pavement is immensely easier to illuminate than a black pavement with a dull mat finish.

Vision by Shadow.—Vision by shadow seems at first thought almost paradoxical. Yet, there are two types of shadows; those that conceal and those that reveal. When seeing by direct light, shades and shadows tend to give the third dimension or volume to an object.

In street lighting, small obstructions on the street, such as bricks or pieces of wood, are seen at least in part by the shadows

they cast. Depending on the angle of the light from the street lamps, the area of the shadow cast by an object may be many times the size of the object itself. These shadows, in general, appear as breaks in the brightness of the pavement and are, therefore, quite closely allied with the silhouette effect, although there is a definite distinction between these two forms of vision. Open manholes and breaks in the pavement also belong in the classification of those things which are usually first seen as dark spots or breaks in the pavement brightness.

Vision by Glint.—Standing water is an important thing to see on the sidewalk or even in the street for it is a good indication of a break in the pavement. It is very often discerned by the reflections of the street lamps on the surface of the water. Likewise the automobile without a rear light is often first located by the glint of light from the glass windows or polished body. Vision by glint indicates, in general, only the location and type of an object.

Evaluating Street Lighting.—From the foregoing discussion of the four methods of vision—by direct illumination, silhouette, shadow, and glint—it is evident that a fair measure of the positive factors in street illumination on the basis of any one of the criteria outlined on page 106 seems quite impossible of attainment. In the opinion of the authors, the criterion of *minimum foot-candles at the darkest point on the street*, although widely used in England, has the least to commend it of any of the criteria proposed; the region of minimum illumination on the street, unless it extends over a large area, has but little to do with vision by silhouette. It will be recalled that even a child on the street may be silhouetted against a bright patch of pavement beneath a lamp nearly a block away. *Average horizontal foot-candles* is important not only in itself as an indication of ability to see by direct illumination but also because, other factors being constant, the brightness of the pavement increases directly with the average foot-candles and thus far there has been no convenient method of evaluating street brightness correctly.

As to *generated lumens per linear foot of street*, it is justly claimed by the proponents of this method that whatever it may lack in other respects, it nevertheless presents a very tangible method of rating and has the advantage of being understandable and readily computed.

Glare.—There are two detracting elements in street lighting which tend to hinder vision in a greater or lesser degree. These, in the order of their importance, are glare and concealing shadows.

Glaring light sources in the field of view actually reduce the ability to see on the street. This effect is much the same as that which would be obtained by placing a screen, such as smoked glass or fine-wire mesh, between the observer and the object at which he is looking.

If a man were actually to wear smoked glasses at night, for equally good vision on the street he would require considerably more light. Likewise, where glaring light sources are present, the level of street illumination must be raised to make up for their blinding or screening effect.

Investigations have indicated that from 25 to 50 per cent of the effectiveness of street illumination is lost, due to this subtractive effect of glare. As a practical demonstration of this fact, one may look at almost any street at night and then note the improved vision obtained by bringing down a shield or visor in front of the eyes so as to eliminate the glare from the street lights. Minimizing the glare is one of the most important considerations in street lighting.

It has been shown by calculations,¹ which check fairly well with earlier observations,² that doubling the height above the eye level of an extended row of light sources cuts the subtractive effect of the glare approximately in half. For example, if on a mile of straight street the light sources are increased in height from 10 ft. above eye level (15 ft. above the pavement) to 20 ft. above eye level (25 ft. above the pavement), the glare will be reduced by approximately one-half. This is not all net gain, however, as far as visibility is concerned, since for a fixed light distribution raising the light source from 15 to 25 ft. above the pavement will decrease the pavement illumination almost as fast as the height above the pavement is increased. The reason is that more of the light then falls outside the limits of the street. A point is soon reached, therefore, at which as much is lost in visibility due to the reduction of illumination on the pavement as is gained by the reduction in glare. This optimum height depends upon the candlepower of the lamp and its light distribu-

¹ HARRISON, W., "Light Without Glare," *Trans. A.I.E.E.*, Vol. 41, p. 439.

² SWEET, A. J., *The Electrical Review*, Mar. 6, 1915.

tion, and in most cases will be found to fall between 20 and 30 ft. above the pavement.

The questions of cost and practicability cannot, of course, be forgotten. Since most modern systems are installed with rigid supports and maintained by tower wagons, the cost is not appreciably more with a 20- to 25-ft. mounting than with lower mounting. On the other hand, above 25 ft. costs mount rapidly especially as existing pole lines will not in general allow greater mounting heights.

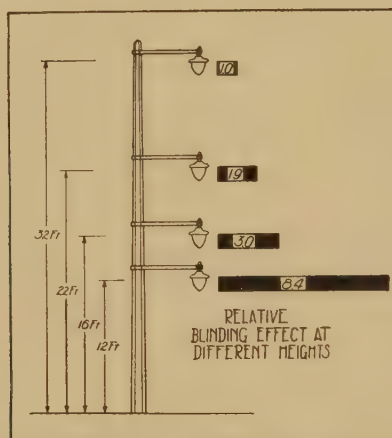


FIG. 88.—A high mounting lessens the glare, but it also reduces materially the illumination on the pavement.

In the street-lighting laboratory at Cleveland, three systems of 10,000-lumen pendent lamps fitted with dome refractors and clear rippled enclosing globes have been set up in order to obtain observers' opinions as to the most desirable mounting height for the system. The lamps are spaced 300 ft. apart on one side of the street and all systems are located on the same posts—the mounting heights of the three systems are 16, 21, and 26 ft. Switching from one system to the other, therefore, gives the effect of raising or lowering the units to the given heights.

The observers are told to look down the street and not up toward the lamps—in other words, to approximate as closely as possible the direction they would ordinarily hold their eyes when driving or walking—and to form an opinion as to which of the systems they prefer after the systems are switched indiscrim-

inately three or four times. Out of some 2,000 observers, about 80 per cent picked the 21-ft. mounting height and the other 20 per cent picked the 26-ft. mounting height. None chose the 16-ft. mounting height. An analysis of the observers' remarks indicated that the 16-ft. height at this spacing and with this size of lamp is too low for eye comfort and best visibility. The units at 21 ft. are more out of the line of vision and offer a material improvement in visibility. The units at 26 ft. offer a further slight gain in eye comfort but the brightness of the pavement surface is materially less, as a smaller proportion of the light falls on the street surface. In the authors' opinion it is quite possible that a thorough investigation of the visibility of small objects on the pavement at various locations would give just as good results with the 26-ft. mounting height as with the 21-ft., although the illumination would be slightly less. Preliminary investigations with smaller lamps and a somewhat closer spacing indicate that this may be true.

Conditions for visibility on the part of the motorist have been improved considerably in modern cars by the lowering of the visor which now cuts out the glare from at least the nearest street lamps. With such visors in use it is practicable to have a sufficiently wide light distribution from the street lamps to give reasonable uniformity on the street, without having the angle of maximum candlepower come within the driver's field of view. In general, this requires a low candlepower between 80 and 90 deg. which can be accomplished fairly well by the use of refractors set for a maximum at 75 deg., in which case the candlepower in the 80- to 90-deg. zone will average about half the maximum candlepower.

Up to this point, the question of glare reduction has been discussed primarily from the standpoint of increasing the mounting height of the units. It is also possible to remove a light source from the direct line of vision by moving it away from the center line of the pavement in a horizontal direction, and this has been advanced by some as a reason for mounting units between the curb lines and the sidewalk rather than over the street. If the light sources are 20 ft. above eye level, however, it can be shown that moving them over 10 ft. sideways only increases the angle between the normal line of vision and the lamp by about the same amount as would be secured if the units were raised 2.2 ft. The reduction in street illumination, on the other hand, is almost as great as though the units had been raised 10 ft. Again,

one cannot always depend upon the reduction in glare anticipated by placing the units back of the curb, for a driver frequently has occasion to look in the direction of the curb line rather than straight down the street.

For the above reasons and particularly because the lamps, when mounted other than above the pavement, involve a great reduction in pavement sheen, the authors recommend bracket mounting for all thoroughfares and residence streets on which light efficiency and economy is a consideration of first importance.

Investigations tend to show that the use, or non-use, of a diffusing globe makes very little difference in the seeing ability of an observer at concentrated attention and that the reduction in ability to see is not dependent to any marked extent on intrinsic brilliancy but rather on total candlepower in the direction of the eye. These glare investigations, however, have all been conducted more or less as laboratory experiments; the observers have been at concentrated attention and the psychological effect of glare was not introduced. When actually driving along a street at night, it is recognized that harsh light sources in the field of view make it so unpleasant or even uncomfortable that it may actually become repellant to concentrate one's attention on the street. Practically, therefore, the harshness of light sources may play a considerable part in reducing visibility.

So far as discomfort is concerned, glare is quite largely a matter of contrast, and in the case of refractor installations an outer envelope tends to soften the sharp line of demarkation between the full candlepower of the refractor and the dense blackness which is often its background.

In addition to the screening effect and the distracting effect of glare, it is invariably true that a system which is soft and comfortable to the eyes, besides providing good illumination, is more dignified and pleasing.

To take extraordinary measures in the design of a street-lighting system in order to minimize glare is largely a matter of planning for the future. Particularly in the case of thoroughfares and downtown business streets it is undoubtedly true that the vast number of automobile headlights encountered causes greater reduction in visibility than does almost any system of street lamps now in use. On the other hand, the alleviation of harshness, the more dignified appearance of the street, and the better distribution of light, are all factors which tend to make a

reasonably high mounting and the enclosure of bright light sources very desirable.

Concealing Shadows.—The negative value of “concealing shadows” is apparent. Unquestionably the most prolific cause of such shadows on both the pavement and sidewalks is trees. Residence streets carry practically the whole burden, although the thoroughfares in the smaller cities are often quite heavily lined with foliage. A mitigating feature in the latter case is

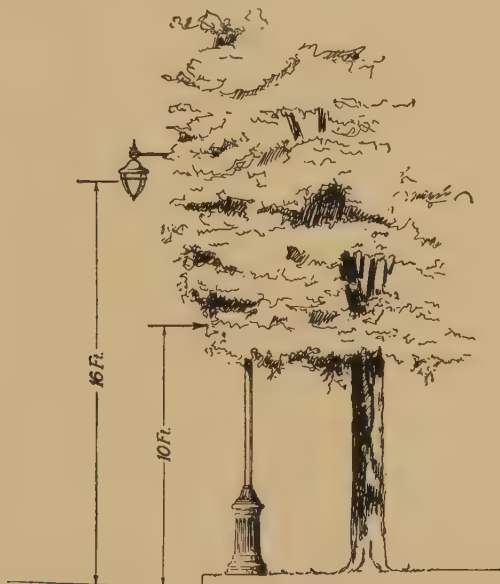


FIG. 89.—There is usually less foliage interference with tall bracket units than with low upright units.

that these thoroughfares have long been the principal streets and consequently the trees are old and their foliage pretty well above the location of the street lamps. The problem, therefore, is confined almost entirely to residence-street lighting.

With upright ornamental units, in the past it has been common practice to adopt a very low mounting height to avoid foliage interference. Even though heights as low as 10 and 11 ft. have been employed, however, interference from the low-hanging branches has not been entirely avoided. Furthermore, extremely low mounting positions greatly reduce the effective spread of light, necessitating very close spacing. At the same time, the light sources are brought directly within the field of view of

drivers, pedestrians, and persons sitting on the porches, so that serious interference with vision and trying glare effects have often resulted. In fact, it is pretty well agreed among street-lighting engineers that rather than adopt such a low mounting height it would be better to lose a portion of the light in the trees in order to obtain the compensating advantages of a mounting height of 15 to 18 ft., as in Fig. 89.

The difficulties encountered with upright ornamental standards are largely obviated by the use of the bracket-type post, with mounting height to light source of 16 ft. or more. This removes the lamps sufficiently from the ordinary range of vision to avoid objectionable glare with lamps of the comparatively low output generally selected for residence streets, while the tree-foliage clearance afforded by the bracket design at this height is often found to be fully as effective as that which would be obtained with a low upright post. Another advantage is that the brackets bring the lamps out from the line of tree trunks in such a manner as to avoid dense tree-trunk shadows parallel with the sidewalk, and bad shadows on the pavement are eliminated. A staggered arrangement of units with the lamps not too far apart is a further insurance against dense shadows, as light is provided from different angles.

In some cases where the foliage is very thick, it is necessary to resort to tree trimming in order to obtain good lighting results. It is fortunate that when foliage has become so thick as to interfere seriously with the lighting the trees are in general old enough to be trimmed without damage.

Summary.—The net illuminating value of any street-lighting installation may be taken as the sum of the factors which assist visibility, less the negative factors—glare and shadows.

The Street Lighting Committee of the Illuminating Engineering Society has attempted to prepare a tabulation of all factors entering into a proper appraisal of a lighting system, including questions of appearance and the community value of a well-lighted street, in addition to those items which have to do directly with visibility.

This appraisal is given in Table XIII. It will be noted that 100 points are given to questions of appearance and 100 points to questions of lighting. No attempt is made to combine these two. Under Value of Lighting the points of view of the motorist, of the pedestrian, and of the occupant of abutting property have

TABLE XIII.—APPRAISAL OF EFFECTIVENESS OF STREET ILLUMINATION

	Maximum Points Allotted	
	Residence Side Street	Traffic Thoro- fare
	Weight	Weight
APPEARANCE		
Daylight appearance of single unit in its environment	30	20
Daylight appearance of street as affected by the street lighting system	30	30
Night appearance of single unit in its environment	20	20
Negative—Glare		
Night appearance of street as affected by the lighting system and by the lighting effect produced	20	30
Negative—Glare		
	—	—
VALUE OF LIGHTING AT NIGHT		
A. To Motorist		
A. Average pavement brightness	23	25
2. Distribution of brightness	11	14
3. Vertical illumination	11	17
Negative—Glare		
B. To Pedestrian Between Curbs In- cluding all Cross Walks		
1. Conspicuity	11	11
2. Visibility	8	8
Negative—Glare		
C. To Pedestrian on Sidewalk		
1. Horizontal illumination	6	4
2. Vertical illumination	8	5
3. Distribution of illumination	9	6
Negative—Glare		
Shadows		
D. To Occupants of Property		
1. Protection afforded	9	7
2. Visibility	4	3
Negative—Glare		
	—	—
Total		

(Taken from the 1927 Report of the Committee on Street Lighting, Illuminating Engineering Society.)

all been considered and various weights given to these points of view depending upon the classification of the street. In the case of the motorist much weight has been placed upon pavement brightness and distribution of this brightness, as being the most important factors assisting vision.

It is the thought of the committee that average pavement brightness, uniformity, average vertical illumination, and average horizontal illumination, will all be determined by measurement and compared with the desirable values established for any given class of street. The ratings will be given in each case with these desirable values as a basis. The ratings thus obtained will then be penalized for the disagreeable and screening effects of glare, and also for concealing shadows. The final summation should give an index of the overall value of the installation.

CHAPTER XI

ZONING OF STREET LIGHTING

It is generally agreed that street lighting has not kept pace with the increasingly rigid requirements imposed by the rapid growth of cities and by the addition of several million motor cars each year on the already congested streets. Where a city now has an unsatisfactory lighting system, however, the reason is not, in many cases, because of the city's failure to appreciate the value of adequate street lighting. Usually it has been due to the lack of a comprehensive plan of development, and to the difficulty of obtaining first-hand experience on the correct solutions of the various problems involved.

Rome was not built in a day—neither is a modern system of city street lighting. And as is true for any large project, the first essential in the development of a good street-lighting system is a thoroughly comprehensive plan. Briefly, this plan should consist of a careful zoning of all the streets in the city into various classifications based on their lighting requirements, and the adoption of a standardized lighting system for each classification.

Zoning the Streets.—The number of street classifications depends to a considerable extent upon the size of the city. A complete zoning of the streets of a large city, whose population is 100,000 or more, usually comprises eight classifications: principal business streets, secondary business streets, principal thoroughfares, secondary thoroughfares, boulevards and parkways, residential streets, alleys in the business sections, and outlying streets and alleys. On the other hand, in a small city whose population is 5,000 or less, it is usually sufficient to have only four classifications: business streets, thoroughfares, residential streets, and outlying streets and alleys.

The determination of the proper number of classifications and the allocation of the individual streets into the various classifications are matters requiring careful study. Consideration should be given not only to existing conditions but also to probable future conditions. Of primary importance, of course,

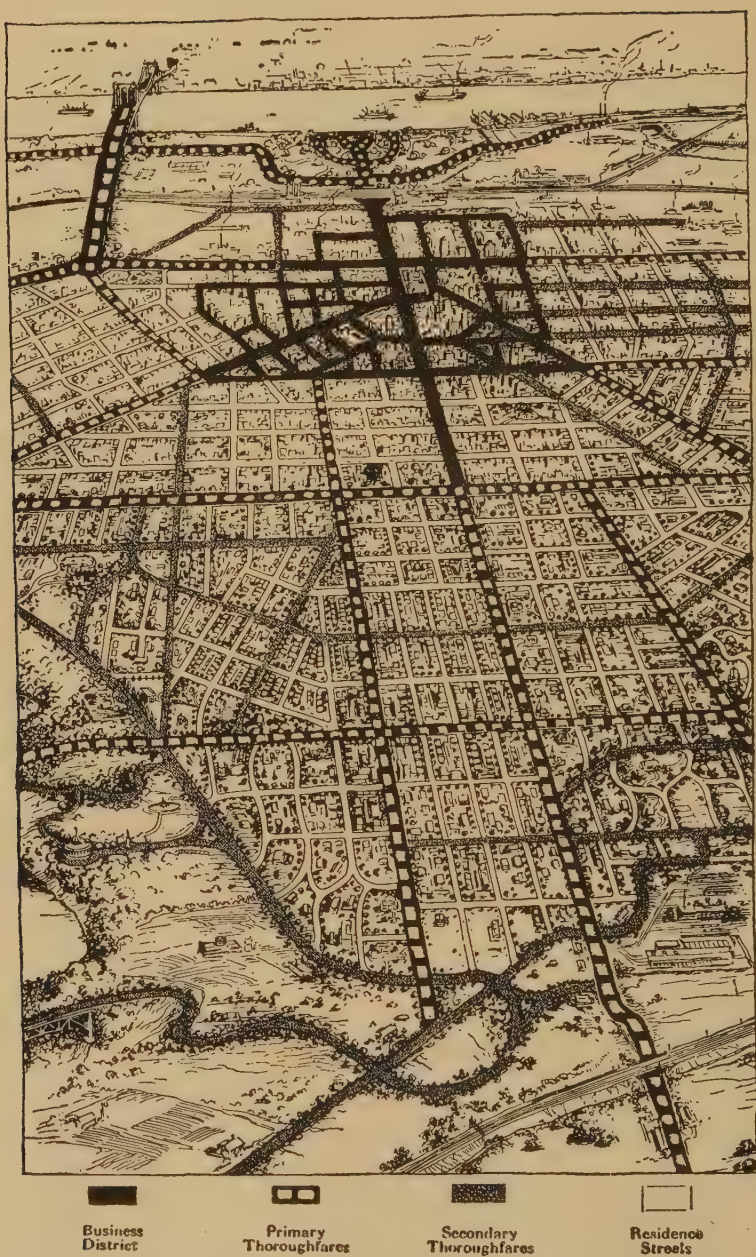


FIG. 90.—Careful zoning of all the streets in the city is the first step in a comprehensive plan of street lighting development.

are such factors as the present type of the structures along a street, the traffic conditions on the street, and its character as regards crime. In addition, the zoning is influenced by such factors as the likelihood that a present residential street may soon become a business street, and the growth of a certain section of the city which may soon make principal thoroughfares out of the secondary thoroughfares to that district. A typical zoning layout for a portion of a city is shown in Fig. 90.

A Standardized System.—Inseparably linked with a comprehensive zoning of a city is the adoption of a standardized lighting system for each classification. Table XIV shows the principal items, such as lumens per foot, mounting height, lamp spacing, etc., which should be covered in these standard systems, and indicates values which represent good practice.

The adoption of a comprehensive plan does not mean that the entire city need be relighted at one time, although in some cases this is practical and has been done, but it does insure that the extensions and revisions made over a period of years will form a part of a unified design. Otherwise, a haphazard variety of conglomerate equipment inevitably results. Such a tangle is happily avoided by using for all classes of streets a "family" of lighting equipment, consisting of globes and posts of similar design but of different dimensions, and with different lamp sizes.

To obtain first-hand experience on which to adopt a standardized lighting system, city officials have found it desirable to visit some sister city in which a far-sighted development program is reasonably complete. Not many cities are in a position to serve as models, however, and in order to cover the subject thoroughly, officials have had to visit several cities, requiring the expenditure of considerable time and money. Even where such a trip is made, much of the advantage of comparison is lost because of the lapse of time and the different conditions under which the various systems are seen.

A more logical method has been developed for the study of street-lighting effects. The city of Cleveland, the Cleveland Electric Illuminating Company, and the National Lamp Works have installed, on a half-mile stretch of street near Nela Park, a street-lighting laboratory which allows the presentation of some 40 different lighting systems. With this full-scale experimental station, pictured in Fig. 91, the different lighting systems which

TABLE XIV.—STREET-LIGHTING PRACTICE

Population of city	Classification of street	Lumens per post	Mounting height, feet	Lamp spacing, feet	Lumens per foot of street		Arrangement of lamps on street
					Minimum	Desirable	
50,000 to 500,000	Principal business.....	15,000 to 50,000	18 to 25	100 to 125	400	400 to 1,000	Opposite
	Secondary business.....	10,000 to 25,000	15 to 18	80 to 125	200	200 to 500	Opposite
	Principal thoroughfares.....	10,000 to 15,000	15 to 20	100 to 150	70	70 to 200	Opposite or staggered
	Boulevards and parks.....	4,000 to 10,000	15 to 20	100 to 150	30	30 to 100	Opposite or one side
	Secondary thoroughfares, wholesale and manufacturing districts.....	4,000 to 10,000	15 to 20	100 to 150	30	30 to 70	Staggered
	Residential.....	2,500 to 4,000	13 to 20	125 to 200	15	15 to 30	Staggered
20,000 to 50,000	Alleys in business section.....	2,500 to 4,000	16 to 20	125 to 200	15	15 to 30	One side
	Outlying streets and alleys.....	1,000 to 2,500	16 to 20	200 to 300	3	3 to 8	One side
	Principal business.....	10,000 to 30,000	15 to 20	80 to 125	300	300 to 500	Opposite
	Secondary business.....	10,000 to 15,000	15 to 18	80 to 125	200	200 to 300	Opposite
	Principal thoroughfares.....	6,000 to 15,000	15 to 20	100 to 150	40	40 to 150	Staggered
	Boulevards and parks.....	4,000 to 10,000	15 to 20	100 to 150	30	30 to 100	Opposite or one side
5,000 to 20,000	Secondary thoroughfares.....	4,000 to 10,000	15 to 20	100 to 150	30	30 to 70	Staggered
	Residential.....	2,500 to 4,000	13 to 20	125 to 200	15	15 to 30	Staggered
	Outlying streets and alleys.....	1,000 to 2,500	16 to 20	200 to 300	3	3 to 8	One side
	Business.....	6,000 to 15,000	14 to 18	80 to 125	120	120 to 300	Opposite
	Principal thoroughfares.....	4,000 to 10,000	15 to 20	100 to 200	30	30 to 100	Staggered
	Secondary thoroughfares.....	4,000 to 6,000	15 to 20	100 to 200	20	20 to 60	Staggered
5,000 or less	Residential.....	2,500 to 4,000	13 to 20	150 to 250	10	10 to 20	Staggered or one side
	Outlying streets and alleys.....	1,000 to 2,500	16 to 20	200 to 300	3	3 to 8	One side
	Business.....	4,000 to 10,000	13 to 16	80 to 110	80	80 to 200	Opposite
	Thoroughfares.....	2,500 to 6,000	15 to 20	100 to 200	20	20 to 60	Staggered or one side
	Residential.....	2,500 to 4,000	13 to 20	150 to 300	8	8 to 15	Staggered or one side
	Outlying streets and alleys.....	1,000 to 2,500	16 to 20	200 to 300	3	3 to 8	One side



FIG. 91.—East 152nd Street, Cleveland—"Forty Streets in One." This half-mile laboratory is devoted to the study and demonstration of lighting systems for residence streets, thoroughfares, boulevards, and highways.



FIG. 92.—Day view of East 152nd Street, Cleveland.

might be installed on residence streets, for example, may be switched on at will and compared directly. Likewise, direct comparison is offered for different thoroughfare lighting systems, boulevard lighting systems, highway lighting systems—everything, in fact, except lighting systems for business streets. This method of comparison, of course, is scarcely applicable to



FIG. 93.—“Lilliput Avenue,” with its designer and builder, E. F. Lumber. This miniature street, in the Nela School of Lighting, is devoted to the study and demonstration of business district lighting.

“white-way” lighting because of the absence of business buildings along the street. Fortunately, “white-way” lighting is something which city officials can judge fairly accurately from inspections of nearby cities or from viewing a “miniature street” such as shown in Fig. 93.

Street lighting is in general purchased by non-technical groups not familiar with the new developments and practice. Contracts are made for a comparatively long period of time, and it is there-

fore of the utmost importance that the buyers—the city officials who represent the taxpayers—be acquainted with what they are buying and the results they may expect in service. It is the authors' opinion that demonstration streets, such as described, are of immense value and that similar streets should be installed in various sections of the country. The large utility companies supplying street lighting to a considerable number of communities in one section of the country might well foster the installation of experimental streets somewhere in their territories. Such installations would, to a great extent, make it unnecessary for each individual city which is purchasing street lighting to have various equipments sent to their particular city for trial installation and would thus relieve the manufacturer, the public utility, and eventually the taxpayer who, of course, must, in the final analysis, assume the burden of cost.

The manufacturers of lamps and street-lighting equipment, by installing exhibitions of ornamental equipment, miniature streets, etc. at their plants, have in the past few years expended great effort to show in simple form the salient principles of modern street lighting.

CHAPTER XII

LIGHTING PLANS FOR BUSINESS DISTRICTS

In business districts, a pleasing and dignified appearance of the lighting equipment is demanded. The system chosen should present no unusual difficulties of installation or operation. The illumination should be sufficient to give maximum safety and convenience both to automobile drivers and pedestrians, with sufficient upward light to illuminate adequately the building facades, including the upper cornices.

The question of the proper size of lamp to be used merits careful consideration. The costs of the ornamental standards, of the underground construction, and of proper maintenance are practically the same for all sizes of lamps, and the fixed charges on these items form a major part of the annual operating cost. The remaining items, namely, energy and lamp renewals, are almost directly proportional to lamp size. The use of larger lamps means that the gain in light received is about twice as much as the increase in total cost.

During the past 15 years there have been radical changes in the practice of lighting business streets. The former idea as to what constituted an ornamental lighting system was a cluster of four or five relatively small lamps. Now the tendency is to install single-light or two-light units on taller, more slender standards. The principal factors underlying this change are that the larger lamps are more efficient, interception of light by the globes in the cluster is eliminated, the street has a more dignified appearance, and the maintenance cost per candlepower is greatly reduced.

In single-light and two-light fixtures, both the globe-type and the lantern-type units have been used with excellent results. The globe-type (Fig. 94) is somewhat more generally chosen. A one-piece globe is lower in first cost, it is more efficient because there are no ribs to intercept light, and it is usually freer from losses due to dirt accumulation on the inside of the globe since it has fewer openings through which dirt-laden air can enter. The use of alabaster rippled glass has material advantages over

the plain white diffusing glass as it is more efficient in the transmission of light and gives pleasing sparkle and animation to the unit.

The use of the lantern type of unit (Fig. 95), particularly in the larger sizes, reduces greatly the hazard from the possible breakage of glass. Obviously, it is much less expensive to renew a broken panel than a whole globe. The lantern type of unit is most adaptable to the use of refractors, where this is desired. Every



(Courtesy of G. E. Co.)

FIG. 94.—Typical globe type of unit.

FIG. 95.—Typical lantern type of unit.

effort should be made to minimize the circulation of air through lantern units; all joints between metal and glass should be felted.

With a unit of any type the most serious losses are from dirt on the inside, since rain keeps the outside fairly clean. To a considerable extent, the advantages of both the globe and the lantern are obtained in equipment consisting of one piece of glassware with a framework of ornamental ribs on the outside.

The question as to whether to use prismatic glass refractors inside the globes or lanterns in ornamental business-district lighting is one upon which there is difference of opinion. The more common practice, especially in the larger cities, is to omit the refractors and allow the upward light to illuminate the upper stories and cornices of the buildings. Certainly, there is not

TABLE XV.—NOTABLE "WHITE-WAY" STREET-LIGHTING INSTALLATIONS
1,000 lumens and above per linear foot of street

City	Street	Lumens per linear foot
Chicago.....	State Street	2,000
Detroit.....	Washington Boulevard and Woodward Avenue	1,900
St. Louis.....	Business District	1,000

500 to 1,000 lumens per linear foot of street

Cleveland.....	Euclid Avenue	900
Jersey City.....	Journal Square Plaza	850
Salt Lake City.....	Business Section	800
Niagara Falls.....	Falls Street	750
Kansas City.....	12th Street	750
Portland.....	Broadway	700
Rochester.....	Main Street	700
Schenectady.....	Erie Boulevard	700
Seattle.....	2nd Avenue	700
San Francisco.....	Market Street	600
Columbus.....	High Street	600
St. Paul.....	6th and 8th Streets	600
Indianapolis.....	Washington Street	600
Oakland.....	Business District	600
El Paso.....	Business District	500

300 to 500 lumens per linear foot of street

Augusta.....	Business District	450
Syracuse.....	Business District	450
Lynn.....	Central Avenue	450
Lansing.....	Business District	400
Atlanta.....	Peachtree, Whitehall, and Marietta streets	400
Washington, D. C.....	F Street	400
Cincinnati.....	Central Parkway	350
Philadelphia.....	Market Street	350
Los Angeles.....	Wilshire Boulevard	350
Utica.....	Business District	300
Saratoga.....	Broadway	300
Omaha.....	Douglas Street	300

NOTE.—To provide 2,000 lumens per linear foot with multiple lamps there must be the equivalent of about 10 1,000-watt lamps every 100 ft.

so great an advantage in their use here as on thoroughfares and residential streets where light in the upper hemisphere is largely wasted and may even be objectionable.

The use of an individual insulating or two-coil transformer in the base of each lighting standard is discussed on page 85. These transformers eliminate the necessity for film cutout sockets, allow the use of the higher amperage (15- and 20-amp.) lamps, insure that only low-voltage wires are brought up into the poles and, in case a pole is accidentally broken and the lead wires



FIG. 96.—Business district lighting in Portland, Oregon; two 1,500-lumen lamps per post, opposite arrangement of units, average spacing about 86 ft.

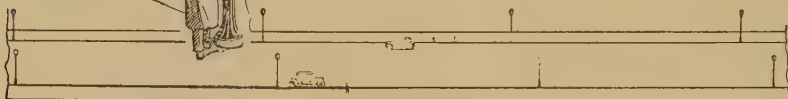
disengaged from the socket, only one lamp is extinguished and not the entire circuit.

Lighting Plans.—The level of illumination desired and the number of units employed for lighting a business street tend to remove “white-way” lighting from the usual characteristics of street lighting and make it comparable in many respects with the lighting of large interiors. Such being the case, it is worthy of note that substantially uniform illumination might be obtained by placing one or, in some instances, two rows of industrial reflectors over the street. With such reflectors, the level of illumination could probably be twice to three times that obtained with regular street-lighting equipment, for a given expenditure of

A. Cities of 50,000—500,000 Population



Number of Lamps per Post	One or two
Size of Lamp	Minimum, one 15,000-lumen lamp per post
	Desirable, two 25,000-lumen lamps per post
Spacing	100—125 ft.
Mounting Height	18—25 ft.
Arrangement of Units . .	Opposite

B. Cities of 20,000—50,000 Population¹

Number of Lamps per Post	One
Size of Lamp	10,000—15,000 lumens
Spacing	90—115 ft.
Mounting Height	15—18 ft.
Arrangement of Units	Opposite



FIGS. 97a and b.—Street-lighting recipes for business districts.

¹ Recipe B is also applicable for the lighting of *secondary* business districts in the larger cities.

C. Cities of 5,000—20,000 Population



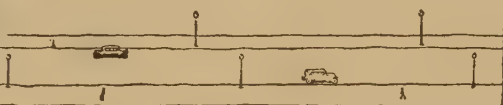
Number of Lamps per
Post..... One

Size of Lamp..... 6,000—10,000 lumens

Spacing..... 80—100 ft.

Mounting Height.... 14—16 ft.

Arrangement of Units. Opposite



D. Cities of Less Than 5,000 Population

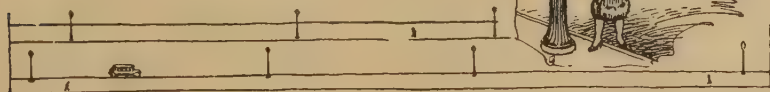
Number of Lamps per
Post..... One

Size of Lamp..... 4,000—6,000 lumens

Spacing... 80—100 ft.

Mounting Height 13—15 ft.

Arrangement of Units. Opposite



FIGS. 97c and d.—Street-lighting recipes for business districts.

money. The disadvantages of this system are that it would not present a very attractive appearance by day, while by night it would lack the interest of an installation of regularly spaced ornamental units at the curb, and in addition the light cutoff would make a sharp line of demarcation on the building fronts, leaving the upper stories in almost complete darkness. In America, these objections have been considered to outweigh the advantages of such a system. In Europe, where the buildings are of a uniformly lower height and no attempt is made to light the upper portions of the building fronts, the disadvantages of this system are relatively less important and many installations of this general character have been made.

Another possibility is the use of very large lamps, up to 250,000 lumens, mounted 50 ft. or more above the pavement and spaced perhaps 400 ft. apart at street intersections. Such units would need to be provided with redirective equipment, of course, to confine most of the light to the street surface and building fronts. No practical installation of such a system has yet been made, but the idea offers possibilities.

In the past, many installations of white-way standards have been made entirely independent of any trolley poles along the street. Now there is a growing feeling that the two sets of poles detract from the appearance of each other, and may even tend to clutter up the street. This is leading to wider use of the combined street lighting and trolley pole standard. Where the smaller lamps are used, single or double brackets are placed on these combination standards below the trolley span wires (Fig. 109, page 141); this limits the mounting height to about 18 feet. Where lamps of the higher candlepowers are used, the poles should be made quite tall and the lighting units should be placed above the trolley span wires, which brings them to a height of about 27 feet. In this latter case two-light fixtures are almost invariably employed. The use of a combination pole makes it possible to obtain a pleasing ornamental standard for no greater expenditure than is required to obtain a conventional street lighting standard and an ordinary trolley pole.

Pages 132 and 133 present recommendations covering the more usual types of installations for cities up to 500 000 population. For larger cities, no specifications for the lighting of the principal business districts have been included, as there are less than a dozen such cities in the United States and each of these requires individual consideration.

CHAPTER XIII

TYPES OF ORNAMENTAL STREET-LIGHTING POSTS

By far the greater percentage of ornamental street-lighting posts made at present are of metal, although concrete has been used to a limited extent in the past and is quite generally considered today.

METAL POSTS

The metal posts in use today may be classified as follows:

1. Pressed steel.
2. Cast iron.
3. Tubular steel.
4. Other types.

Pressed-steel Posts.—Pressed-steel posts are sectional in construction, with the shaft and base and top casting as separate units. The shaft is of two-ply rust-resisting sheet steel, ordinarily 22 gage. The base is of cast iron, in one or more parts. Tie rods embedded in the concrete foundation extend up into the base and anchor the standard to the ground. Other tie rods pass from the base through the shaft and into the top casting, which supports the casing and glassware. According to the manufacturer, this construction affords "great strength, light weight, and low center of gravity." The pressed-metal sectional construction undoubtedly provides a comparatively light-weight post of good strength and wearing qualities which will not break off and fall to the ground if struck by a moving vehicle. In case of an accident, it is rarely necessary to replace more than one or two sections of the standard.

In addition to the pressed standard described, there is also available similar equipment of heavy-duty construction in which the shaft is made of a single thickness of heavier metal. The shaft is anchored directly to the concrete foundation, without employing tie rods, and an ornamental base may be added if desired.

Where unusually rich effects are sought, the pressed-steel shafts may be covered with cold-rolled sheet copper which can be supplied in various finishes.

Cast-iron Posts.—Cast iron has always been used extensively in the manufacture of street-lighting posts, usually of one-piece construction. Its durable qualities and strength, together with the fact that there is no limit to the number of different designs that can be made available, have undoubtedly contributed much to its popularity. One manufacturer who specializes entirely on street-lighting standards has developed a special cast iron which it is claimed has superior strength and better molding qualities than the ordinary cast iron of commerce.

In the case of tall cast-iron posts which otherwise would offer considerable hazard should they be broken off, the manufacturers provide a form of internal steel reinforcement which not only prevents a broken section of post from falling but also is designed to yield somewhat under heavy impact and thus protect the post from breakage.

Both the pressed-steel and the cast-iron posts are easily adaptable to combination trolley-pole and lighting-standard construction for the intensive or "super-white-way" lighting of business districts in the larger cities. With either type of equipment, a suitable trolley pole is simply encased by the cast-iron or pressed-steel post. The heavy-duty pressed-steel posts, previously mentioned, have shafts sufficiently strong to serve as trolley poles.

Tubular-steel Posts.—Tubular-steel posts have been used to a somewhat limited extent for upright units. Here their strength and low cost are of advantage, but their appearance has not been sufficiently pleasing to enable them to compete with the other more ornamental types. There does, however, appear to be a field for the tubular-steel post for bracket-pendent equipment with underground construction for ornamental lighting on thoroughfares and residence streets.

In many of the smaller communities, the business district is confined principally to one street, and this street often has trolley poles on it for either an interurban railway or a street-car line. Obviously, these trolley poles can be equipped with brackets mounting "white-way" lighting units, thereby eliminating the expense of another set of poles. Further, as the trolley poles already carry feeder lines for the trolley wire it is not imperative

that the street-lighting circuits be installed underground—without seriously detracting from the general effect, they can be strung along the tops of the poles and brought down through each pole and out the bracket to the lighting unit. Such a system for the smaller communities is simple, comparatively inexpensive to install, and, if care is chosen in design, quite satisfactory from the standpoint of appearance and lighting results.

The manufacturers have developed suitable brackets and bases for the trolley poles which add much to the attractiveness of the installation. Care should be taken in any system of this kind to see that the trolley poles are plumb—otherwise the brackets will not be horizontal and a haphazard appearance will result.

Other Types of Metal Posts.—Street-lighting posts of expanded and fabricated steel have found very occasional use. Appearance seems to be the limiting factor with these types of posts.

CONCRETE POSTS

Concrete street lighting posts may be obtained in a variety of pleasing designs and color textures. Their use has, in general, been confined to the lighting of thoroughfares and residence streets, and it is the authors' opinion that it is in these fields that they are the most applicable. There have been at least two installations worthy of note—in Milwaukee and St. Louis—where tall, two-light concrete posts have also been employed for the lighting of the business districts.

The manufacturers appear to differ as to the desirable method to be used in making concrete posts for permanency. There are two widely used processes. In one process the metal form containing the concrete and reinforcing rods in position is rotated rapidly on a horizontal axis, and centrifugal force presses the mixture against the wall of the form. In the other process the form is vertical and concrete is added slowly and is carefully packed around the reinforcing by jogging or tamping.



FIG. 98.—The "Nela White-Way," an exhibition of various types and makes of ornamental street-lighting equipment.



FIG. 99.



FIG. 100.

FIG. 99.—Form 12 Novalux Unit with No. 126 alabaster rippled-glass globe and canopy, made by the General Electric Co. Union Metal Mfg. Co. pressed steel standard, Design No. 4237. 2,000-watt Mazda C lamp. Height to light source $27\frac{3}{4}$ ft.

FIG. 100.—Paragon Senior Top with alabaster rectilinear glass globe, canopy, and Edgewater "15" cast-iron post with duplex extension, made by the Westinghouse Electric & Mfg. Co. 15,000-lumen Mazda C lamp. Height to light source 20 ft.



FIG. 101.



FIG. 102.



FIG. 103.

FIG. 101.—Form 9 Novalux Unit with No. 118 alabaster rippled-glass globe and canopy, made by the General Electric Co. Union Metal Mfg. Co. pressed-steel standard, Design No. 1927. 15,000-lumen Mazda C lamp. Height to light source 20 ft.

FIG. 102.—Form 12 Novalux Unit with No. 124 alabaster rippled-glass globe and canopy, made by the General Electric Co. King Mfg. Co. cast-iron standard, French Design No. 64. 15,000-lumen Mazda C lamp. Height to light source 20 ft.

FIG. 103.—Form 9 Novalux Unit with No. 126 alabaster rippled-glass globe and canopy, made by the General Electric Co. Union Metal Mfg. Co. pressed-steel standard, Design No. 2153. 25,000-lumen Mazda C lamp. Height to light source 18 ft.



FIG. 104.



FIG. 105.



FIG. 106.

FIG. 104.—Corona Senior Top with alabaster rectilinear glass globe, canopy, and cast-iron post, Design Arcadian 15, made by the Westinghouse Electric & Mfg. Co. 15,000-lumen Mazda C lamp. Height to light source 16 ft.

FIG. 105.—Form 23 "B" Novalux Lantern Unit with Colonial alabaster glass panels and dome refractor, made by the General Electric Co. Union Metal Mfg. Co. pressed-steel standard, Design No. 842. 15,000-lumen Mazda C lamp. Height to light source 15 ft.

FIG. 106.—Form 16 Novalux Unit with light alabaster rippled-glass globe, canopy, and dome refractor, made by the General Electric Co. King Mfg. Co. cast-iron standard, Design No. 45. 15,000-lumen Mazda C lamp. Height to light source 15 ft.

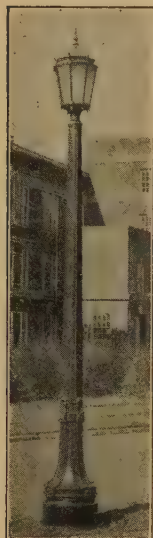


FIG. 107.



FIG. 108.



FIG. 109.

FIG. 107.—Form 18 "B" Novalux Lantern Unit with clear stippled-glass panels and dome refractor, made by the General Electric Co. King Mfg. Co. cast-iron standard, French Design No. 62. 15,000-lumen Mazda C lamp. Height to light source 15 ft.

FIG. 108.—Form 16 Novalux Unit with No. 37 Genco glass globe and metal canopy, made by the General Electric Co. Electric Railway Equipment Co. tubular-steel standard, Design No. 10814A. 15,000-lumen Mazda C lamp. Height to light source 13½ ft.

FIG. 109.—Form 16 Novalux Unit with No. 118 alabaster rippled-glass globe and canopy, made by the General Electric Co. Electric Railway Equipment Co. combination railway and light standard, Design No. 10462. 10,000-lumen Mazda C lamp. Height to light source 15 ft. Length of bracket arm 2 ft.



FIG. 110.

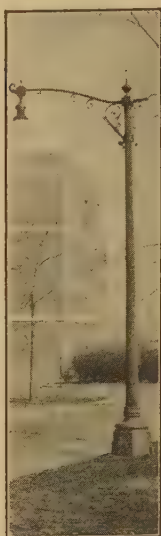


FIG. 111.



FIG. 112.

FIG. 110.—Form 24 "B" Novalux Lantern Unit with Colonial alabaster glass panels and dome refractor, made by the General Electric Co. Union Metal Mfg. Co. pressed-steel standard with bracket, Design No. 1106. 10,000-lumen Mazda C lamp. Height to light source 18 ft. Length of bracket arm $2\frac{1}{2}$ ft.

FIG. 111.—Form 32 Novalux Unit with No. 146 light alabaster rippled-glass globe and dome refractor, made by the General Electric Co. Union Metal Mfg. Co. pressed-steel standard, Design No. 2729. 10,000-lumen Mazda C lamp. Height to light source 21 ft. Length of bracket arm 7 ft.

FIG. 112.—Form 25 "B" Novalux Basket-style Unit with light alabaster rippled-glass globe and dome refractor, made by the General Electric Co. King Mfg. Co. tubular-steel standard, Design No. 1454. 10,000-lumen Mazda C lamp. Height to light source 19 ft. Length of bracket arm 4 ft.



FIG. 113.



FIG. 114.



FIG. 115.

FIG. 113.—Octagonal Reflecto-Lux Junior Lantern with stippled-glass panels, parabolic reflectors, and cast-iron standard, Design Gothic 12, made by the Westinghouse Electric & Mfg. Co. 4,000-lumen Mazda C lamp. Height to light source 13 ft.

FIG. 114.—Form 8 Novalux Unit with No. 123 light alabaster rippled-glass globe, canopy, and dome refractor, made by the General Electric Co. Union Metal Mfg. Co. pressed-steel standard, Design No. 1292. 4,000-lumen Mazda C lamp. Height to light source $13\frac{1}{2}$ ft.

FIG. 115.—Form 30 Novalux Unit with No. 135 light alabaster rippled-glass globe, metal canopy, and dome refractor, made by the General Electric Co. American Concrete Marbelite Co. concrete standard, Design City of Chicago. 4,000-lumen Mazda C lamp. Height to light source 13 ft.



FIG. 116.



FIG. 117.



FIG. 118.

FIG. 116.—Form 17 Novalux Harp Unit with No. 120 light alabaster rippled-glass globe and dome refractor, made by the General Electric Co. King Mfg. Co. cast-iron standard, Design No. 45. 4,000-lumen Mazda C lamp. Height to light source $14\frac{1}{2}$ ft.

FIG. 117.—Milwaukee Harp One-piece Glass Refractor Unit, made by the Holophane Glass Co. Metal fixture parts made by the Line Material Co. Westinghouse Electric & Mfg. Co. hollowspun concrete post, Design No. Sheridan 13. 4,000-lumen Mazda C lamp. Height to light source 15 ft.

FIG. 118.—Form 25 "A" Basket-type Novalux Unit with light alabaster rippled-glass globe and dome refractor, made by the General Electric Co. Union Metal Mfg. Co. tubular-steel standard, Design No. 1360. 4,000-lumen Mazda C lamp. Height to light source 16 ft. Length of bracket arm $4\frac{1}{2}$ ft.

CHAPTER XIV

LIGHTING PLANS FOR THOROUGHFARES

Thoroughfares or arterial traffic streets leading out from the business to the residential sections in the large cities, and the streets in smaller cities which are portions of main highways, have developed severe requirements for lighting under the present traffic conditions. These streets contribute a large proportion of night-traffic accidents, largely due to the fact that they carry automobiles driven at a relatively high speed by those who often are unfamiliar with the street.

The illumination on thoroughfares and arterial streets should be such that an automobile driver, when moving at the highest permissible rate of speed, will be able to see a grown person or child in the street, or about to step from the curb into the street, in ample time to avoid accident; also that small obstructions or depressions will be clearly revealed. Passengers should be able to gage their footing quickly as they step on and off street cars, and they should be clearly visible to the oncoming motorist. It should be possible to read written addresses anywhere on the street.

In the days of the horse-drawn vehicle it was considered that a thoroughfare was adequately lighted if there was one arc light of 3,000 lumens or thereabouts over each street intersection. Such a location in the center of the street has the advantage of being the position from which the highest percentage of the generated lumens can be delivered to the street surface. On the other hand, whatever the level of illumination employed, the center-span system always has the disadvantage that it is difficult and even hazardous to maintain the units under the present traffic conditions. Furthermore, as a street becomes more important and has two or more lanes of traffic, the street lights are actually more effective when they are mounted on bracket arms over the two lanes of traffic rather than over the center of the street. Today, therefore, there are two approved systems of thoroughfare lighting, both of which provide adequately for two or more lanes of traffic.

The first system is an extension of the business-district lighting on these streets. The urgency of economy, however, usually dictates a somewhat lower expenditure per mile. Where this is the case, the practice is to omit every other lamp, leaving a staggered arrangement of units.

The second system employs tall standards with bracket arms and pendent lighting units. The bracket-type standard has the virtue of bringing the lamp out over the street surface, thereby increasing the utilization of light and reducing foliage inter-



FIG 119.—Main thoroughfare lighting in Cleveland, Ohio; 15,000-lumen lamps, pendent equipment, asymmetric dome refractors, staggered arrangement of units, one unit per 150 lin. ft. of street.

ference. The lamp, when over the pavement, is of tremendous value in increasing the driver's ability to see objects by silhouette against the bright area of light beneath the lamp and against the glint reflections or sheen from the pavement surface; also, both curbs are more distinctly revealed. In general, on a thoroughfare, two such bracket standards, properly located, are equivalent in illuminating value to three upright "white-way" standards carrying lamps of the same size. For greatest effectiveness, the bracket should be 6 ft. or more in length, although considerations of appearance may sometimes result in a compromise; the shorter the bracket the less effective is the lighting, especially on wide streets.

Units on thoroughfares may be glaring at a mounting height which is entirely satisfactory in the business districts. In the business districts, the light sources are viewed against a bright background composed of lighted buildings, show windows, and electric signs, and the contrast between the bright units and their background is relatively much less than on the thoroughfares where the background is, in general, very dark. Glare depends to a large extent upon the degree of contrast between the light source and its background. This fact, together with the wider



FIG. 120.—Ornamental lighting on a Cleveland parkway; 10,000-lumen lamps, units on one side of parkway, average spacing 200 ft., symmetrical dome refractors.

spacing, tends to make it desirable to mount the units somewhat higher on the thoroughfares.

On thoroughfares there are few, if any, building fronts which need to be lighted because of æsthetic considerations. The use of auxiliary redirective equipment, such as prismatic glass, concentrates most of the light on the street surface and is, therefore, of advantage.

In general, the problem in the lighting of boulevards is not far different from that involved in the lighting of thoroughfares. In both cases, most of the traffic is vehicular rather than pedestrian, and there are seldom any buildings along the roadway.

A. Cities of 50,000—500,000 Population



Number of Lamps
per Post One

Size of Lamp 10,000—15,000 lumens

Spacing 100—150 ft.

Mounting Height

Upright Unit 15—18 ft.

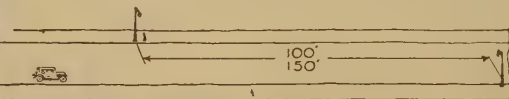
Bracket Unit 20—25 ft.

Bracket Length 6 ft. or more

Arrangement of

Units Staggered

One unit for every 100—150 ft. length of street

B. Cities of Less Than 50,000 Population¹

Number of Lamps per
Post One

Size of Lamp 4,000—6,000 lumens

Spacing 150—200 ft.

Mounting Height

Upright Unit 15—18 ft.

Bracket Unit 20—25 ft.

Bracket Length 6 ft. or more

Arrangement of Units. Staggered

One unit for every 150—200 ft. length of street

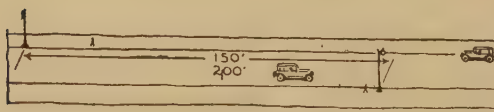


FIG. 121.—Street-lighting recipes for thoroughfares.

¹Recipe B is also applicable for the lighting of *secondary* thoroughfares in the larger cities.

This means that the greater portion of light may be used most effectively by directing it to the pavement, and refractors having an asymmetrical distribution may well be employed.

The traffic on boulevards is seldom as heavy as on principal thoroughfares, but more nearly approximates that on the secondary thoroughfares. The lighting system, therefore, which is applicable to the secondary thoroughfares, quite often meets the requirements of the boulevards, except from the standpoint of appearance. Since most boulevards pass through the better districts of a city, ornamental standards are usually required.

CHAPTER XV

LIGHTING PLANS FOR RESIDENCE STREETS

Where residence streets carry a large amount of through traffic they are, in effect, thoroughfares and should be lighted as such. In every city, however, there is a large percentage of street mileage, in strictly residential territory, which is not



FIG. 122.—Residence street lighting in East Cleveland, Ohio; 150-watt lamps, multiple distribution, dome refractors, staggered arrangement of units, one unit per 150 lin. ft. of street.

used for through travel and, therefore, is not subject to any great amount of high-speed traffic. While the lighting requirements are not as severe as on the thoroughfares, nevertheless the illumination should insure that obstructions and serious breaks or defects in the pavement will be revealed, that children playing in the street will readily be seen by an automobile driver when

going at a fair rate of speed, and that turns, dead ends, and street intersections will be definitely marked. Any unsure footing in sidewalks should be rendered visible, dense shadows from trees should be minimized, and all street signs and at least an occasional house number should be discernible. Enough light should be provided on front lawns to avoid dark spots, particularly near the sidewalk, which might afford convenient concealment for thieves and thugs, but at the same time, care should be exercised that equipment does not appear unduly bright from porches.

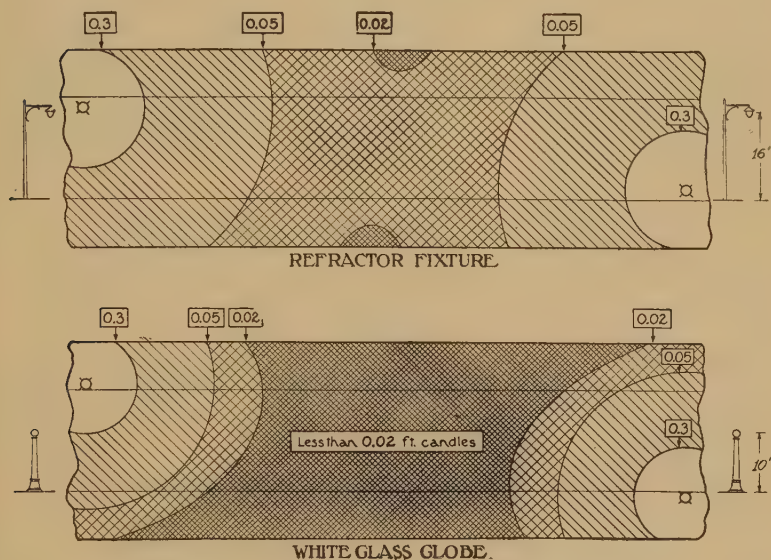


FIG. 123.—Comparison of light utilization. A pendent bracket unit with refractor *versus* an upright globe of white glass.

A staggered arrangement of units is desirable in order to lessen tree-trunk shadows and to provide equal illumination on both sidewalks. So far as the roadway is concerned, the bracket unit has the same advantages on residence streets as on thoroughfares and, here again, the use of prismatic refracting equipment results in more efficient utilization of light. The refractors, particularly those of the asymmetric type, serve another advantageous purpose in that they reduce the amount of light on the porches and in the upper windows of residences.

When gas was the almost universal illuminant for residence streets, the height of the gas lamps was usually limited in practice

A. Cities of 50,000—500,000 Population

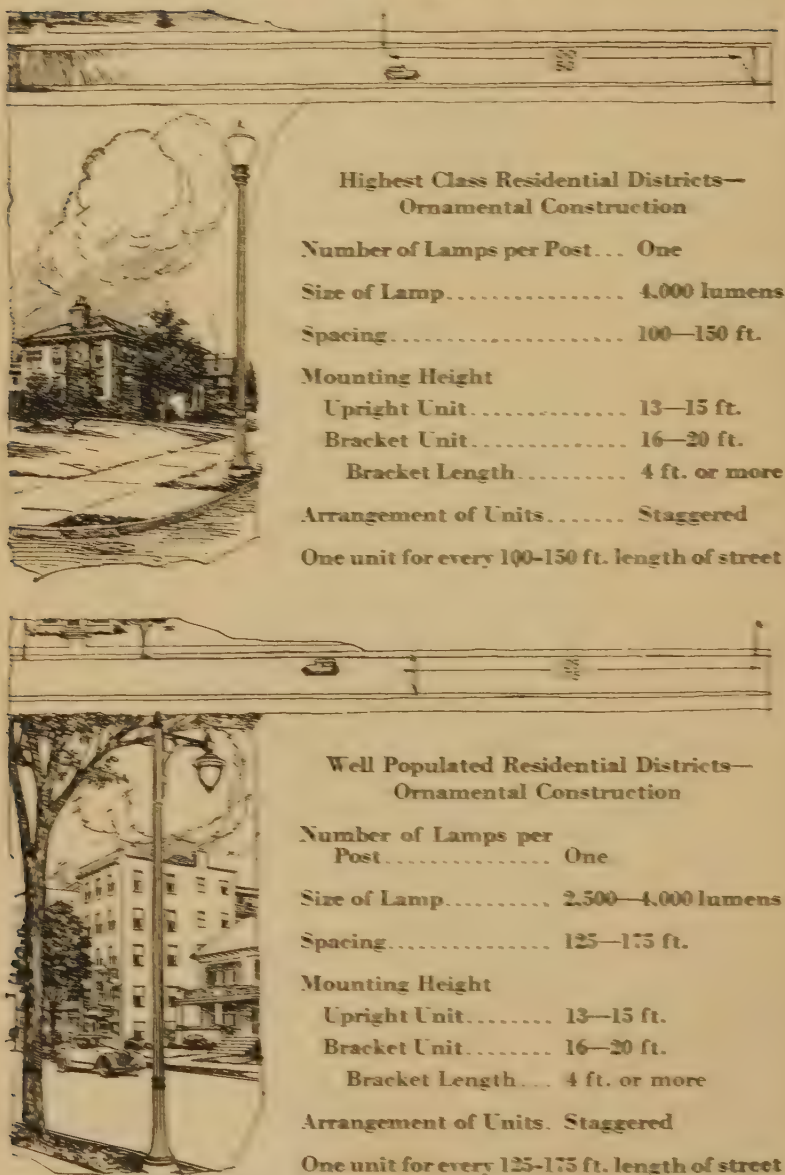


FIG. 124a.—Street-lighting recipes for residence streets.

B. Cities of Less Than 50,000 Population

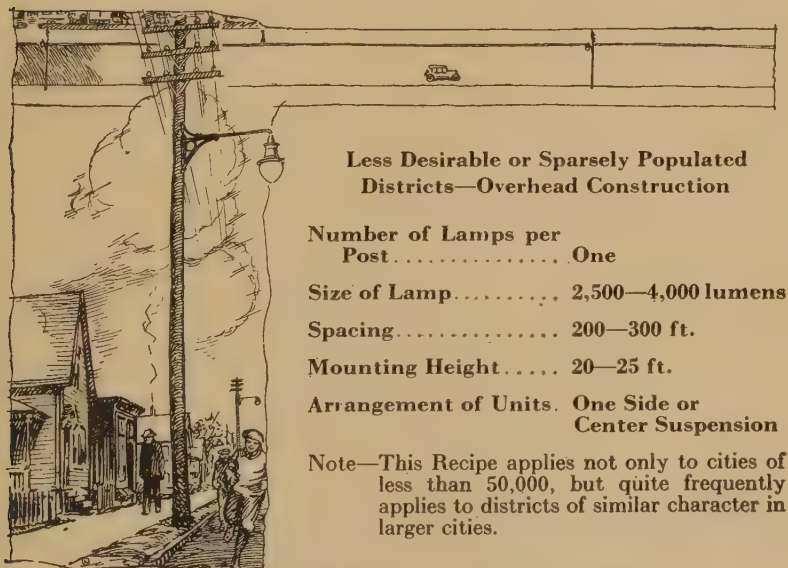
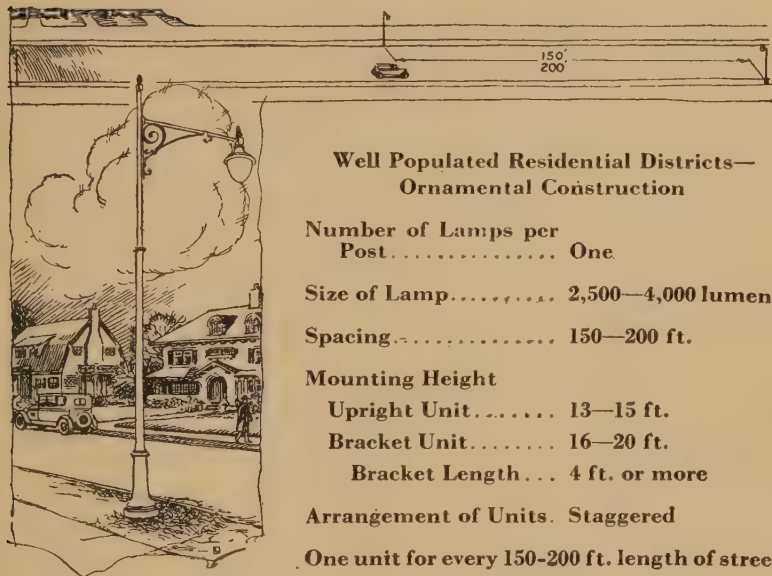


FIG. 124b.—Street-lighting recipes for residence streets.

to 8 or 9 ft. in order to facilitate lighting them. Later, when competitive installations of electric lamps were put in, their height was generally increased to 10 or 11 ft. This mounting height met the needs of the pedestrian fairly well, and the argument that it avoided interference with foliage is still used to some extent. Surveys have proved, however, that in most cases a minimum mounting height of 13 ft. for upright units and 16 ft. for bracket units is satisfactory, especially as it is not, in general, difficult or undesirable to trim the lower branches of trees where they interfere seriously. The greater mounting heights remove the light sources farther from the line of vision and also allow a more economical first cost and maintenance cost per mile of street as the light spreads farther and consequently fewer units of larger size can be used. Figure 123 illustrates the difference in utilization of light between a system of modern high-efficiency ornamental pendent units and a system of upright opal balls.

CHAPTER XVI

HIGHWAY LIGHTING

Night pleasure driving and motor trucking are increasing at a rate which is causing an insistent demand for safety and convenience on the highways at night comparable with that of the day. Without the important developments in motor-vehicle lighting and the legislation governing the use of headlamps which have come about during the past few years, night driving would by this time have become intolerable. The scope of these developments is limited, however, by road and service conditions, and legislation cannot demand the impossible. Without some other provision for lighting, a headlamp with a single fixed beam—the predominant type now encountered—must always be aimed so high as to be a potential source of glare.

H. E. Butler¹ has summarized the important advantages of highway lighting as follows:

- I. Prevents accidents:
 - (1) By showing up dangerous curves.
 - (2) By reducing headlight glare.
 - (3) By illuminating signs, sides of roads, and obstacles.
- II. Adds to comfort of night driving:
 - (1) By relieving eyestrain.
 - (2) By assisting in making repairs.
 - (3) By discouraging holdups.
- III. Increases night traffic and thereby relieves day congestion.
- IV. Decreases running time and increases road capacity.
- V. Helps to bring electricity to the farm by providing a pole line.
- VI. Increases real estate values:
 - (1) By tending to extend the city along highways.
 - (2) By bringing electrical conveniences.

When we think of highway accidents we usually visualize an automobile lying overturned in the ditch, or two machines which have collided. However, a detailed study by I. C. Plummer, Chief of Division of Vital Statistics, State of Ohio, has shown that the pedestrian and not the motorist is the one who suffers

¹ BUTLER, H. E., *Gen. Elec. Rev.*, August, 1922.

in the great majority of highway accidents. During the first ten months of 1928, 66 motorists were killed when their cars left the highway and overturned, and 39 died as a result of colli-



FIG. 125.—Types of highway lighting units which have an extremely concentrated distribution of light and, therefore, should be mounted at least 30 ft. above the ground to avoid objectionable glare.

sion with other vehicles. Nearly all of the remaining 344 fatal accidents on the highways of Ohio were due to pedestrians being run down by automobiles.

One reason for the heavy toll among highway pedestrians is, of course, that there are seldom any sidewalks in the country and people must therefore walk on the roadway. The other factor is the usual lack of highway lighting. It is significant that, in spite of the much smaller number of vehicles and pedestrians on the road at night, more than half of all the highway accidents occur at that time—relatively twice as many as occur in cities where reasonably good street lighting is provided.

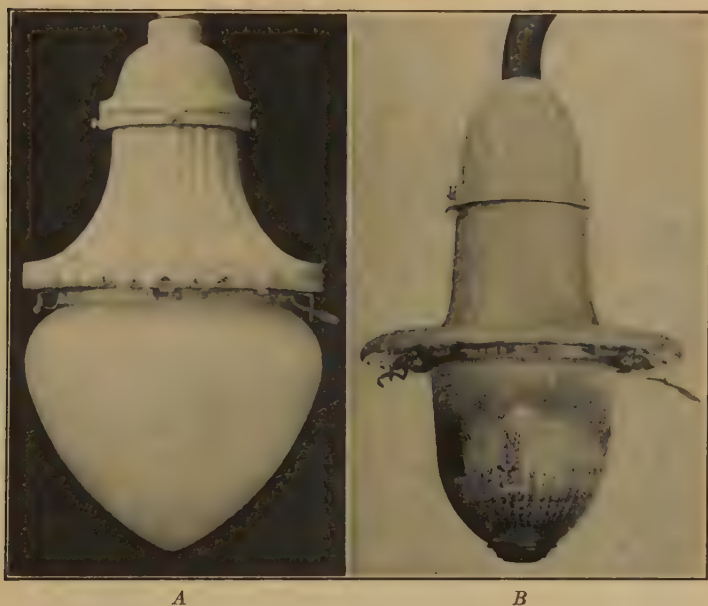


FIG. 126.—Types of highway lighting units which may be mounted only 20 to 25 ft. above the ground. - (Courtesy of G. E. Co.)

(a).—Rippled globe with asymmetric refractor. (b) Asymmetric bowl refractor with ripples on the outside—no outer globe.

While most of the automobile traffic on state highways is of city origin, the great bulk of the pedestrian traffic on the same highways is of rural origin, and from the standpoint of accident hazard the lighting of heavily traveled stretches of roadway is of greater moment to the latter than to the former.

The problem of lighting a highway is not strikingly different from that of lighting a city street, and undoubtedly any lighting system which would be satisfactory for a city thoroughfare would be equally satisfactory, from the standpoint of illumination, on the highway. In fact, some of the super-highways which are

being installed should be lighted as thoroughfares since their requirements are practically as rigid.

On the other hand, there are a number of highways which are quite narrow, do not have intersecting streets, and also are not built up to any extent. On these roads, economy dictates a minimum expenditure, and, therefore, the trend has been toward the development of equipments which would utilize comparatively small lamps (usually 2,500 lumens) and direct as much of the available light as possible to the pavement. Fig. 125 illustrates several equipments that have been used for this purpose.

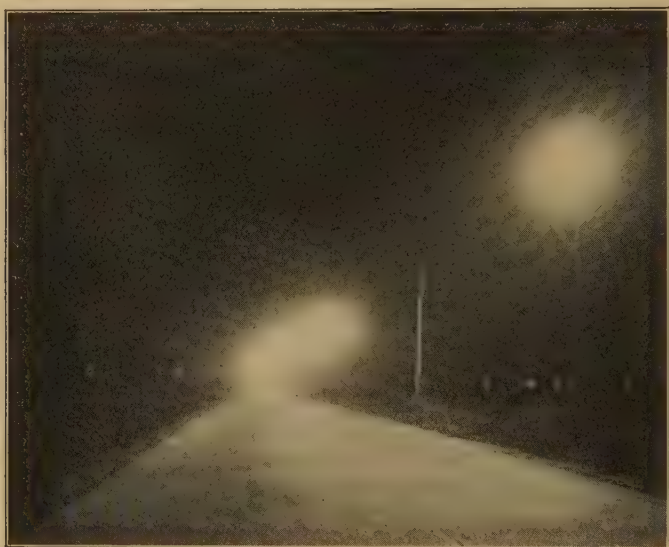


FIG. 127.—Highway lighting installation on Hylan Boulevard, Long Island.

The arguments in favor of equipments of this type are that they are the most effective for ribbon-like roads where light to the side would simply be wasted in illuminating adjacent fields. Because of their extreme concentration of light, however, where these units are equipped with 2,500-lumen lamps it is necessary to mount them at least 30 ft. above the ground to avoid objectionable glare. The usual spacing is about 300 ft.

The disadvantages of a 30-ft. mounting are greater first cost and more difficult maintenance. In general, mounting heights greater than 25 ft. are not popular with operating companies and are considerably more expensive to maintain. It appears that

for a majority of highways a type of equipment similar to ordinary city street lighting fixtures and utilizing lamps of 2,500 to 6,000 lumens has advantages.

An equipment of this kind, which has found satisfactory application to highway lighting, is an asymmetric refractor and rippled globe combination such as is illustrated in Fig. 126A. Another is an asymmetric bowl refractor without an outer globe but with ripples on the outside of the refractor such as shown in Fig. 126B.



FIG. 128.—Wider Woodward, a well-lighted "super-highway" leading north from Detroit.

Lighting Recommendations.—Most country highways have a pavement width of less than 30 ft. On such highways, satisfactory lighting can be provided with a single row of units properly located. Others classed as double highways have an overall width from outside to outside of the pavement of 50 ft. or more. Here, to provide satisfactory illumination, at least two rows of lighting units properly located are necessary. Highway widths between 30 and 50 ft. are less commonly encountered and for satisfactory results require either center suspension or two rows of units.

Perhaps the most difficult and important problem in highway lighting is that of a satisfactory location of the lighting unit with respect to the edge of the pavement. For reasons of safety, and sometimes on account of legislative enactment, the electric-

transmission poles are usually placed a long ways back from the pavement. On such a pole, a bracket only a few feet long means that the best-lighted section of the right of way is not the pavement but rather the dirt section between the pavement and the pole. Obviously, it is desirable either to place the pole closer to the pavement or to use a bracket arm up to 16 or 18 ft. in length, which will bring the lamp at least to the edge of the pavement.

Just as in the lighting of city streets, the pavement surface on the highway is a controlling factor in the amount of illumination desirable for adequate visibility. This is discussed on pages 107-111. Dull-black, oil-bound macadam makes a surface which is almost impossible to light adequately with the appropriations usually available.

It is the consensus of opinion among engineers that 300 ft. is about the proper spacing for narrow roads with a single row of lighting units. If the spacing is stretched much beyond this figure, it will be found that the illumination becomes spotty with dark areas midway between the lamps. On the other hand, if the requirements of the traffic are such that it is necessary to provide more light, it will be found more economical to increase the size of the lamp at the 300-ft. spacing than to use a greater number of small lamps at shorter intervals. In the case of sharp curves and particularly of blind turns, it may, of course, be necessary to shorten the spacing considerably.

The double highway should be lighted as two independent single highways—that is, with a row of units on each side of the highway approximately 300 ft. apart, but staggered so as to bring one unit for every 150 lin. ft. of roadway. On the less important roads whose width still requires two rows of units, the spacing may be stretched to 200 or 225 ft. measured along the center line of the street.

No lamps of less than 2,500 lumens should be considered for highway lighting, since even with this lamp the energy cost is materially less than half the total annual operating cost.

In many states suitable legislation must still be adopted before highway lighting can be installed and operated. The bill in Appendix D is one prepared and sponsored by the Good Roads Federation of Ohio and presented before the Ohio General Assembly. Differing from other bills in several states, which simply allow the cost to be provided through county funds, this bill provides a means whereby the state may cooperate in the financing.

CHAPTER XVII

PRACTICAL RULES FOR THE LOCATION OF LIGHTING UNITS

A review of Chap. X will show that such matters as glare, pavement brightness, uniformity of illumination, and silhouette depend largely on the location of the lighting units—their height, their spacing, and their positions transversely of the street. The following practical rules for the proper locations of lighting units are based on the principles set forth in this earlier chapter:

1. A 30-ft. pavement (curb to curb) should be considered as about the limit for a satisfactory installation of overhead thoroughfare or residence street lighting with units on only one side of the street. Where a permanent installation consisting of ornamental underground lighting equipment is adopted, even though the pavement width is less than 30 ft., the small additional cost of staggering the units is a very profitable investment. Most streets of this character are lined with trees and the staggered system avoids long heavy shadows and provides the same amount of illumination on both sidewalks.

2. In thoroughfare and residence street lighting it is noteworthy that even with efficient upright equipment two bracket standards properly located are generally equivalent in illuminating value to three upright standards carrying lamps of the same size. The pendent-bracket equipment has a greater output in the lower hemisphere; also the bracket, by bringing the unit over the curb, reduces the apparent width of the pavement, and gives a bright spot of light under the lamp and a path of brightness along the curb which is of great importance in assisting the driver to see by silhouette.

3. Wherever practical, lamps should be placed on the outside of a curve; otherwise, they are directly in the driver's view and he cannot readily see past them. Also, with lamps on the inside of the curve the direction of the light is such that there is no sheen of brightness on the pavement to assist the driver's vision.

4. A staggered system of lighting is not desirable for a boulevard with sharp curves unless the units are very close together

and afford a high level of illumination. The staggered system does not indicate the direction of the road nearly as well as do units on only one side or on both sides opposite each other. Where lamps are located on one side of the road only, and it is desirable to cross to the other side with the row of units on account of foliage interference or curves, a pair of units may be located opposite each other at this point to avoid confusion.

5. The center-suspension system of overhead lighting is not, in general, recommended because it is difficult to maintain under present conditions of traffic, and on wide streets it does not afford maximum visibility by silhouette as the sheen off the pavement does not cover the entire surface but is seen simply as a bright strip at the center of the street.

6. Where ornamental upright units are used, 13 ft. should be considered a minimum mounting height even with lamps of small size. Where 2,500- or 4,000-lumen lamps are used with ornamental pendent bracket equipment, 15 ft. should be considered a minimum. Where 6,000- to 15,000-lumen lamps are used for thoroughfare lighting in pendent equipment, 20 ft. should be considered a minimum. Where lamps even as small as 2,500 lumens are used on a spacing of 250 ft. or over, a mounting height of 20 ft. should be considered a minimum.

7. The adherence to a fixed spacing for ornamental equipment on any given street need not be absolutely rigid. If the spacing adopted is 150 ft. and this places one unit directly in the foliage of a tree, the unit should be moved one way or the other to clear the branches. With a spacing of 150 ft., if the distance between units varies as much as 20 ft. the casual observer will not notice it.

8. A lamp should be placed at the head of a dead-end street to reveal a danger point to the driver and allow him time to stop without overrunning.

9. Street-lighting posts should be located at least 18 in. from the curb in order to clear overhanging truck bodies, automobile bumpers, etc.

10. Curbs in the business district are now being built with a rather long arc at the corners in order to facilitate automobile turning. Previously where square corners were used it was possible to locate a unit directly on the corner and it would line accurately with each row of units on the intersecting streets. With the long-radius curbs a unit located right at the corner does

not line up with either row of units and also it congests the available cross-walk space. Consequently, the practice now is to locate such a unit on the principal street at the property line. A unit so located usually provides sufficient light for the side street, although if the side street is quite important it is easily possible to bring the first units on the side street closer to the corner, say one-half the regular spacing.

Additional practical rules and recommendations are given in the *Rules of Street Lighting* prepared by the Street Lighting Committee of the Illuminating Engineering Society and included as Appendix C at the end of this book.

CHAPTER XVIII

CABLE—OVERHEAD AND UNDERGROUND

The purpose of this chapter is not to discuss materials and methods of line construction in detail, but simply to consider those factors that are closely related to the cost and the reliability of operation of a street-lighting system.

Wire used for overhead street lighting is generally No. 6 solid copper conductor. Here, current-carrying capacity is not the principal criterion by which the wire is chosen, as a conductor of smaller cross-section would generally transmit the current for the street lamps without economic waste. Rather, it has been quite general experience that No. 6 is the best compromise between first cost and sufficient tensile strength to hold up under adverse conditions. Where it is desired to make use of wider pole spacings than are practicable with No. 6 copper wire, copper-clad steel wire has sometimes been employed because of its greater strength.

The standard insulation for the overhead wire consists of three braids impregnated with black weatherproof compound. This same covering is used for all voltages. Protection from ground is provided by means of porcelain or glass insulators on the poles and in the street-lighting units.

With underground construction, the choice of cable is a more involved problem. It is generally conceded, however, that with the series circuits of 6.6 amp., No. 8 wire is the logical choice as to size, although No. 6 is sometimes used. Insulation is a prime consideration and standard cable may be obtained in voltages from 600 up to 8,000 volts—the higher the voltage insulation, the greater the cost. An idea of how the cost of cable varies with the size and insulation is shown in Fig. 129. The degree of insulation necessary is governed by the maximum or open-circuit voltage obtained from the secondary of the constant-current transformer to be used on the circuit. These data may usually be found in the transformer manufacturer's handbook.

The usual cable for street-lighting circuits employs a lead sheath over the requisite insulation, the purpose of which is to

make the cable waterproof. Cable in this form gives satisfactory performance except for the hazard of mechanical injury. To guard against such injury, the lead may be wrapped with a layer

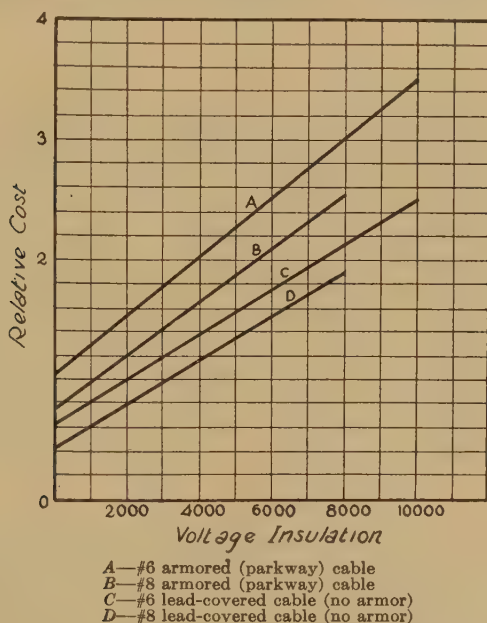


FIG. 129.—Relative cost of underground cables.

of jute, then with two layers of steel taping, and finally with an outer jute covering; a cable of this type is shown in Fig. 130.

When once in place, cable armored in this way will stand

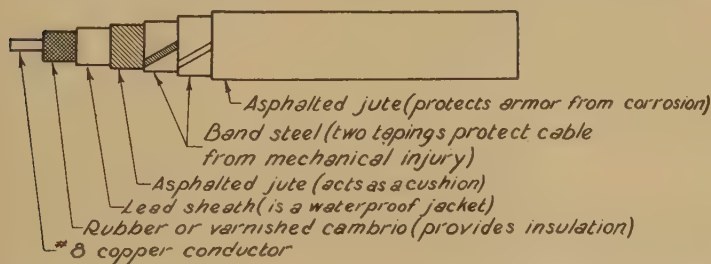


FIG. 130.—Usual type of cable employed in underground street-lighting circuits.

a considerable amount of abuse. Where the cable is laid in sod, it is the usual practice to bury it in a trench from 18 to 24 in. beneath the surface. Armored cable used in the business dis-

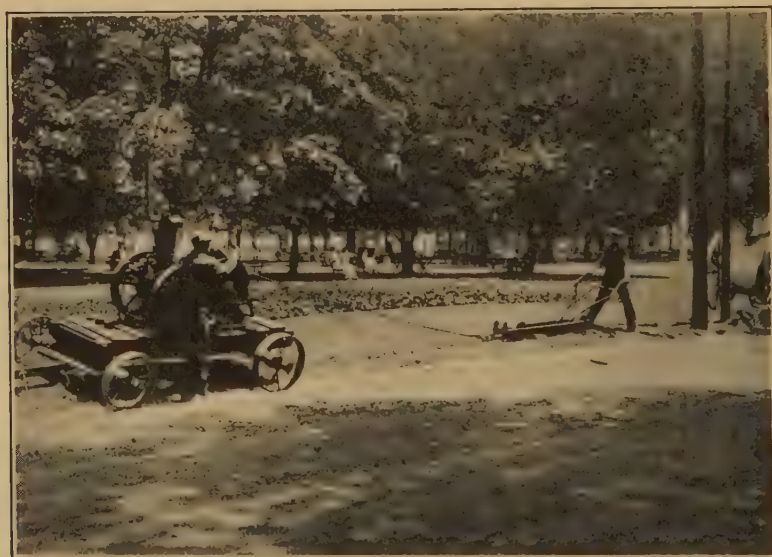
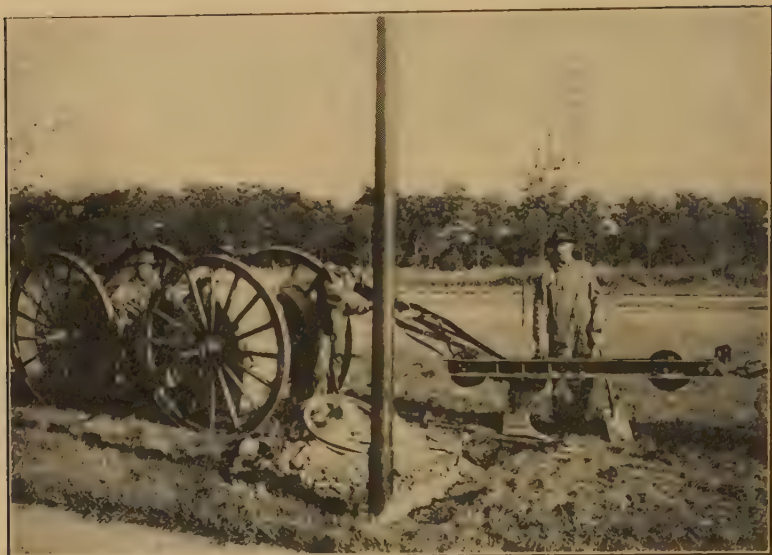


FIG. 131.—The "Philadelphia Cable Plow," which lays underground cable without the necessity of digging and filling a trench. (Courtesy of Philadelphia Electric Co.)

tricts where there are no tree lawns may be sealed up in a channel cut in the existing concrete sidewalk or in the pavement adjacent to the curb. Where it is run across the street, it is generally pulled through an iron pipe so that if necessary this section can be replaced without tearing up the street.

Another common form of underground construction consists of lead-covered cable without the steel sheath; the cable is drawn into a conduit, usually a 3-in. fiber duct buried to a depth of about 18 in. This is a somewhat more expensive installation than the armored cable laid directly in the ground, but has the advantage of easier replacement should defects develop. In some cases, lead cable has been buried in the ground with no protection except that afforded by a jute covering and perhaps a board laid over it before the trench was filled.

During recent years a number of new types of cable have been tried out for underground service in an endeavor to secure the waterproofing quality of the lead and protective qualities of the steel sheath without the use of either of these metals. These new cables are less expensive than the older types and some have been found to withstand severe tests.

Labor for excavation is a large item in the expense of an underground installation and much thought has been given to reducing this cost. One method used with notable success in Philadelphia employs a cable plow, as shown in Fig. 131. The blade of this plow extends about 18 in. below the surface and one end of the cable is attached to the bottom of this blade so that it is drawn in at the same time the cut is made. An important advantage of this plow is that it obviates the necessity of removing and relaying sod in the tree lawns and the premises of those from whom easements have been obtained.

Where difficulty has been encountered with underground-cable installations, it may often be traced to lack of care in laying. Lead-sheath or armored cable cannot be bent on a small radius without injury, and for connection to other wires should be brought well up into the base of the post so as to guard completely against the entrance of moisture into the insulation. For the latter reason it is customary not to cut the cable at the time of laying but to allow ample loops at each post location to be connected later when the installation of the posts is completed.

CHAPTER XIX

SYSTEMATIZED MAINTENANCE

It might be said that a street-lighting system is properly maintained when the street lamps are in service at all times that light is required, and are operated so as to give practically their initial light output.

Before discussing the various factors involved, it may be well to consider the importance of proper maintenance of a street-lighting system, using an actual installation as an example. When the installation referred to was put in, it was considered to be one of the best in the country. After it had been in operation for approximately a year, however, even to the casual observer the amount of light emitted by the units was far below that supplied when the system was first turned on. The appearance of the units when lighted indicated that the glassware was dirty, and also that the lamps were burning considerably under rated efficiency.

In order to determine just what percentage of the decrease in candlepower should be attributed to the various factors involved, photometric and electrical measurements were made on sample units. Candlepower measurements of the equipment as found, and when thoroughly cleaned with soap and water, were taken. The current through the lamps was checked, and the old lamps found in the fixtures were brought into the laboratory for lumen rating. Accurate electrical measurements showed that the lamps were burning at slightly less than rated amperage, and accordingly the central-station meter was recalibrated. An inspection of the lamps indicated that some had burned much longer than their rated life, and the consequent blackened bulbs and sagged filaments gave evidence that they were operating at a very low efficiency.

Fig. 132 indicates the weight of the various factors accountable for the decrease in efficiency of the system. Although 6,000-lumen lamps were used in this installation, the photometric measurements showed that the light output of a typical fixture,

as found, was only equivalent to the output which would be obtained with an 1,850-lumen lamp operated at rated current in a clean fixture. By washing the lamp and glassware, the equivalent lamp size was increased to 4,000 lumens, an increase of 116 per cent. The substitution of a new lamp raised the equivalent lamp size to 5,200 lumens, a further increase of 30 per cent. With the correct current through the lamp, the light output was increased still another 15 per cent and was brought up to the rated value, 6,000 lumens. Thus, as a result of neglected maintenance, this system was delivering only about one-third the light it would have delivered under good operating practice.

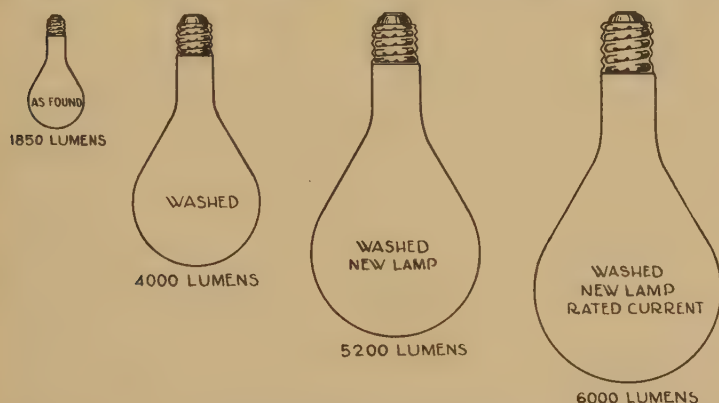


FIG. 132.—An actual example showing the amount of light which may be lost through neglected maintenance.

Burning Hours.—Present practice is tending toward the standardization of the 4,000-hr. all-night, every night schedule, as any schedule with less burning hours does not adequately meet the requirements. Under such a schedule, the lamps are on from approximately 15 min. after sunset until 30 min. before sunrise. The savings in the schedules which are a modification of this one are but meagre because only the coal cost and lamp renewals are, in general, affected.

With the increasing mutual confidence between public utilities and the communities they serve, it is believed that the time is coming when the hour of turning street lamps on and off will not be so rigidly fixed as it is in some of the printed schedules. Certainly, it is true that on dark, rainy evenings the lamps ought to be turned on earlier than on clear evenings. Perhaps the

ultimate solution lies in a contract whereby, in addition to the burning hours called for by a printed schedule, the company agrees to furnish say 100 additional hours of service distributed throughout the year on evenings when darkness falls prematurely.

Rated Amperage.—Care should be taken to maintain the current through the lamps at their rated amperage. The serious decrease in light output accompanying even a small decrease in current is shown in Fig. 40, page 52.

Lamp Outages and Depreciation.—From the standpoint of the city, lamp outages are objectionable because they leave an area in darkness. Also when a street lamp fails, the central station suffers through loss of good will, a special trip must be made to replace the lamp, and the contract may call for an hourly penalty.

In contrast with lamp outages, the losses due to lamps falling off in candlepower are more subtle and often more serious. The great majority of incandescent lamps have well maintained lumen outputs throughout life (see pages 47 and 51). However, it takes but a few individual lamps in which the filaments sag and slump in candlepower to make a street lighting system unsatisfactory, unless there is some plan for removing dim lamps from the circuit. For example, in a 100-lamp circuit there may be only one lamp of the original lot in which the filament will sag, but because of its low filament temperature this lamp may live for a year or two. Then in the replacement lot for the other 99 sockets another such lamp may appear. Thus it can be seen that during the course of time the circuit may become pronouncedly spotted with dim lamps.

The answer to the question of outages and lamp depreciation as worked out by a number of progressive central stations is the removal of lamps from the sockets before burnout. Such practice may consist of keeping an accurate record of the life of all lamps individually, and when any lamp has been burned for perhaps 20 per cent longer than its rated life, it is replaced with a new one. Such a system, of course, takes care of dim lamps and also removes from the circuit a number of lamps that are undoubtedly on the verge of failure. Other systems call for a sectionalizing of the city and keeping a record of the number of outages reported per day in each section. When the outages per day for any section rise above a certain figure determined by experiment, all the lamps in that section are replaced. Or, instead of basing the time of "sweeping change" on the number of outages, it may

be based on the rated life of the lamps. The lamps removed are brought back to the station for inspection, and those with pitted filaments, blackened bulbs, or sagged filaments are scrapped. The rest, which to all external appearances are good, are put in reserve for replacement of early burnouts in the new installation.

The operation of this latter plan may involve the breaking up of a small number of lamps capable of giving service for several hundred hours. It should be borne in mind, however, that a lamp worth \$2 when new is worth only about 30 cts. when it has 200 hr. life left in it, and it is far cheaper to sacrifice this 30 cts. worth of life than to make a special trip to replace a burnout.

Patrolling.—Practice in different cities varies widely in the matter of patrolling. In some cities, the central station employs men who ride through the city all night, covering every street at least once looking for burned-out lamps. The other extreme is to have no patrol at all, but to have an arrangement with the city whereby the policemen who patrol the streets report directly to the central station any lamps that are out. In still other cities, the central station patrols the more important streets, particularly the ornamental lighting district, and depends upon the police or local residents to report lamps that are out on the streets of lesser importance.

Patrolling is, of course, an unproductive expense, but with the older illuminants an adequate patrol was almost essential for good service. With incandescent lamps, particularly where all the lamps are cleared off the lines as outlined above, outages may be reduced to less than one per fixture per year and nightly patrolling becomes less important. It is, obviously, more sound economically to spend the money for more frequent cleaning of the glassware or for lamps of higher candlepower, rather than for patrolling.

Glassware Cleaning.—With arc lamps it was necessary to replace electrodes anywhere from once a day to once a month, depending upon the type of equipment used. When this was done, it was a simple matter to clean the globes at the same time; consequently, arc-lamp glassware has in general been very well maintained. With the incandescent system, on the other hand, the lamps used need replacing only about three times a year and as a result there has been a tendency toward laxness in keeping the units clean, because cleaning meant a special trip. The example of neglected maintenance mentioned in the first part of

this chapter, however, emphasizes the fact that it pays to follow a systematic and regular cleaning schedule.

Street-lighting units should be washed thoroughly with soap and water or some other cleaning compound from four to twelve times a year, depending on the location and the type of equip-



FIG. 133.— Street-lighting maintenance truck used by the Cleveland Electric Illuminating Co.

ment. Attention is called to the fact that not only is there a wide range in the atmospheric conditions in different cities, but also there is considerable variation in different localities in the same city. Further, it is obvious that the nearer the units are to being dust-tight and bug-proof the less they will depreciate in light output over a given period. A few extra dollars spent to secure a fixture of this type will pay for itself many times over in additional candlepower delivered. Where best appearance of the lighting equipment is important and yet the atmospheric conditions are extremely unfavorable, as in the business districts of some large cities, it may be desirable to wash the units thoroughly every two weeks. Likewise, periodic painting of metal or wooden posts and cleaning of concrete posts is necessary if the installation is to look its best.

In this connection, the following data on the depreciation of outdoor lighting equipment, presented before the Illuminating Engineering Society, by Anderson and Ketch, in 1924, is of material interest and value. The location of the street-lighting equipment during the test period was on the roof of a building. A railroad with a fairly heavy traffic passed the corner of the building within a few hundred feet of the test location. The lamps were lighted two 2-hr. periods each day.

Table XVI gives a description of the equipment included and the depreciation measured at the end of the test period. The

results on units *C* and *F* demonstrate the value of closed dust-tight fixtures in reducing the depreciation due to the collection of dust, as compared with units having globes with holes in the bottom. Holes were necessary when globes were used on old arc-lighting equipment, to supply air circulation and ventilation to carry off the fumes. Incandescent lamps require no such circulation of air and many thousands of street-lighting globes having bottom holes would be more efficient if the globes were without holes.

TABLE XVI.—DEPRECIATION TEST ON OUTDOOR LIGHTING EQUIPMENTS

Lighting unit	Percentage of depreciation	
	Relative	Actual
<i>A.</i> Nested parabolic enameled-steel reflectors.....	100	41.2
<i>B.</i> Flat enameled-steel reflector, bowl refractor, closed bottom.....	85	34.9
<i>C.</i> Ventilated fixture, dome refractor, clear rippled globe, hole in bottom.....	83	34.2
<i>D.</i> Dome refractor without globe.....	69	28.3
<i>E.</i> Light opal eight-panel hinged top lantern, dome refractor.....	68	27.9
<i>F.</i> Dust-tight fixture, one-piece cast top, felt globe gasket, dome refractor and light rippled globe—no hole in bottom.....	58	23.8
<i>G.</i> Radial fluted enameled-steel reflector.....	37	15.3

Specifying Maintenance.—There are two ways of specifying maintenance. One is for the city simply to require that the units be well maintained. The other is to set forth specifically all of the maintenance procedure which must be followed by the central station. As an example of a contract which sets down in detail almost every conceivable requirement, the following section on maintenance in a recent street-lighting contract is given:

To prevent and remedy outages, the Company shall establish and maintain an efficient system of patrol for inspecting all lamps in such streets and ways, and any lamp which fails to burn properly shall be promptly reported and put in order, or immediately replaced. For such inspection a sufficient number of men shall be employed to make an examination of each such lamp as often as reasonably

required by the Board of Public Works, and the Company shall use all due effort to secure such inspection. Any broken globes or reflectors shall be replaced by sound ones as soon as possible after the same are broken, and while any globes or reflectors remain broken and not replaced, the lights shall be considered as out, and such outages may be deducted from the price of such lights. The Police Department will report daily to the Engineer all outages and the duration thereof so far as observed or known by the members of said Department, and said Engineer shall in books of the City, to be kept in the office of the City Engineer, make and preserve a record of all light outages. The Company shall each day before twelve o'clock noon, make a written report to the City Engineer, stating the number and locations of any lamps extinguished or not burning on the preceding night, if any; the time when each lamp was reported extinguished or not burning, and the time the lamp was relighted and started burning; and the said report shall also state the cause of each said lamp being extinguished or failing to burn and if any of the said lamps are extinguished by reason of the failure of the current to supply said lamps, or for any reason, his report shall contain a statement of the cause of such failure to supply current.

For every lamp which is out for more than sixty consecutive minutes, the Board of Public Works may impose upon the Contractor a deduction for that night which is equal to one-hundredth of the annual price for said lamp which would have been paid to the Contractor, had the lamp operated satisfactorily. These sums shall be deducted from the amount due or which may become due to the Contractor under any contract; of which these specifications may form a part, unless such failures result from causes beyond the control of the Contractor. For every lamp which is out for more than sixty consecutive minutes, from causes beyond the control of the Contractor, the Board may impose upon the Contractor a deduction for that night which is equal to one-fourth-hundredths of the annual price for said lamp which would have been paid to the Contractor had the lamp been operating.

The foregoing provision, with reference to causes beyond the control of the Contractor, is intended also to provide for the situation which might arise by reason of any order or requirement of the Federal Government, or other authorities duly authorized, limiting or prohibiting the use of electric current for street lighting. In case the order of the government, or duly authorized authority, forbids city lighting in toto, or for any given number of lamps, then no payment shall be made by the City of——— for such lamps as are not burning during the period of the order. If the order of the government, or other authority, limits and restricts the burning

of light during certain hours of the night, then payment shall be made upon the basis bid for the 2,000-hour or midnight service, or upon such reasonable proportion of such bid as may be just and reasonable and as agreed upon by the City and the Contractor, or determined by the Public Service Commission of the state of _____as provided for in the Contract.

Whenever for any cause there is a failure to light the City, or any districts therein, for a period of one night or more, no payment shall be made by the City for the lamps out during said period.

The voltage and amperage supplied to each lamp shall be such as to maintain the lamps according to the standard requirements of the manufacturers.

Each lighting circuit shall be equipped with a testing loop at such place and in such manner as the Board and the Contractor shall jointly determine in order that the Board may at any time make tests as to the fluctuations of the current supplied. The Board or their representative shall, at all times, have access to the testing loop and to the stations or other places on the Contractor's property where the Board may desire to make inspections or tests. In case of a dispute between the City and the Contractor as to the accuracy of any meter or other instrument used in making tests or measurements of the Contractor's service, said instrument may be tested either in the City's laboratory in the presence of a representative of the Contractor, or in the Contractor's laboratory in the presence of a representative of the City, at the option of the Board, or the Board and the Contractor may agree to have such instrument tested by a Laboratory of recognized standing.

The City of _____shall indemnify and hold the Contractor harmless from all injuries and damages to persons and property by reason of said inspections or tests, except for injuries or damages caused by the negligence of the Contractor.

Whenever tests made by the Board show that the amperes upon any lamp circuits have been below the standard for those circuits for any unbroken period of one-half hour in any night as evidenced by the readings of a graphic recording ammeter or other device, then the Contractor shall deduct from his bill a sum equal to five cents per night for each lamp on those circuits tested of 2,500 lumens and smaller and ten cents per night for each lamp on these circuits tested of larger than 2,500 lumens.

Whenever tests made by the Board show that the voltage supplied to any arc lamp has been below the standard prescribed for those lamps for an unbroken period of one-half hour in any night as evidenced by the reading of a graphic recording voltmeter or other device, then the Contractor shall deduct from its bill the sum of 25 cents per night for each of said lamps so tested.

The Board shall report to the Contractor the following morning the results of any tests showing deficiencies. The Contractor shall be permitted to examine and inspect the charts of the meters used in such tests.

The deductions to be made for low amperage or voltage under the provisions of this section are to be treated not as a penalty, but as liquidated damages for failure to perform the contract.

The incandescent lamps supplied by the Contractor and used for lighting the streets, avenues, alleys, subways, squares, bridges and public places under the 4,000 burning-hour schedule of this contract shall be removed from the lighting fixtures and replaced with new lamps of the same lumen output within 10 days before April 1, Sept. 1 and Dec. 20, of each year. Incandescent lamps in fixtures operating on the 2,000-hour schedule shall be replaced with new lamps as soon as possible after having burned 1,350 hours. Each incandescent lamp before being reset shall be stamped by the City Engineer, or his duly authorized representative with a suitable stamp giving the date of installation. Any lamp removed which from date stamp shows same has been in service less than 700 burning hours may be used by the Contractor in new fixtures erected between renewal periods or to replace lamps which have burnt out or been broken, but in no case shall such a lamp be used until again stamped by the City Engineer or his duly authorized representative, with date of installation.

If the Board shall find upon inspection any incandescent lamps burning under this contract which have been in service longer than 1,500 burning hours as shown by the date stamp then the Board shall impose upon the Contractor a deduction which shall be equal to the number of excess burning hours multiplied by one-two-thousandth of the annual price for said lamp.

The above renewal periods are based on a burning-hour life efficiency for incandescent lamps of 1,350 hours which period it is agreed is the present standard burning-hour period. Whenever the manufacturers find it possible and desirable to produce an incandescent lamp, under guarantee which will give the present standard of performance over a longer period the above renewal periods may be changed by mutual agreement between the Board and the Contractor.

If, in the opinion of the Board, any lamp is not giving service according to the light guarantee of the manufacturer, the Contractor shall on request replace said lamp with one satisfactory to the Board.

Should the Contractor fail to make satisfactory replacement, the Board may remove the lamp in dispute and test or have same tested for the average total lumens which it delivers.

If the result of the test shows the lamp to be defective, in accordance with the standard guaranteed by the manufacturer, the Contractor shall, within 48 hours, after receiving notice of the result of said test, substitute for said lamp, one satisfactory to the Board.

Should the Contractor fail to replace the lamp in accordance with the provisions contained in paragraph above, then said lamp shall be considered as out and subject to deduction for outage until such substitution is made.

All glassware used in connection with the lamps under this contract shall be kept clean and free from dirt, dust, or other accumulations . . .

Glassware on incandescent lamps shall be cleaned as often as required by the Board to preserve the efficiency of the light, provided every lamp is thoroughly cleaned at least once a month.

All ornamental standards and fixtures must be painted two coats of paint in such color as directed by the Board and such painting shall be done as often as required by the Board to preserve a good appearance.

One of the authors' criticisms of this elaborate form of contract is that it requires practically duplicate patrol—by the city police force and by the central station—and that the money thus expended might better be invested in more adequate street lighting. Also, a central station bidding upon this contract would, in estimating its costs, probably need to make a liberal allowance for unusual losses, penalties, etc., as stipulated in the contract.

CHAPTER XX

OPERATING COSTS

In determining the total operating cost of a street-lighting system, three general classifications of charges should be considered:

1. Fixed charges, which include interest on the investment, insurance and taxes, depreciation of permanent parts, and other expenses which are independent of the number of hours of use. Often these charges form a large part of the total operating expense, yet they are only too frequently omitted from cost tables.

2. Maintenance charges, which include renewal of parts, labor, and all other costs except the cost of energy.

3. The cost of energy, which depends upon the hours of burning and the rate charged.

It must be recognized that street-lighting operating costs are a summation of items which vary widely, and no effort will be made to achieve the impossible—that is, to fix cost figures for the operation of various sizes of street lamps. Labor, for example, is a large item and this cost is far from constant for different cities even in the same locality. Again, a system utilizing standardized equipment will have a lower operating cost per lamp than will a system comprising numerous types of equipment. Whether the system is patrolled to locate burned-out lamps or whether these are reported by the police force and residents will affect the total annual operating cost. And how well the system is maintained is another factor which affects its cost somewhat and its value tremendously.

The items which enter into the cost of operation of electric street lamps are given and explained in Table XVII. Most of the items in this table pertain to what might be termed the purely electrical features of a system, although in "white-way" installations the cost of ornamental standards and of underground construction is often sufficiently large so that the fixed charges on

these items represent a substantial part of the total operating cost. On the other hand, such items are sometimes financed in another way, in which case they may not be included in the computation.

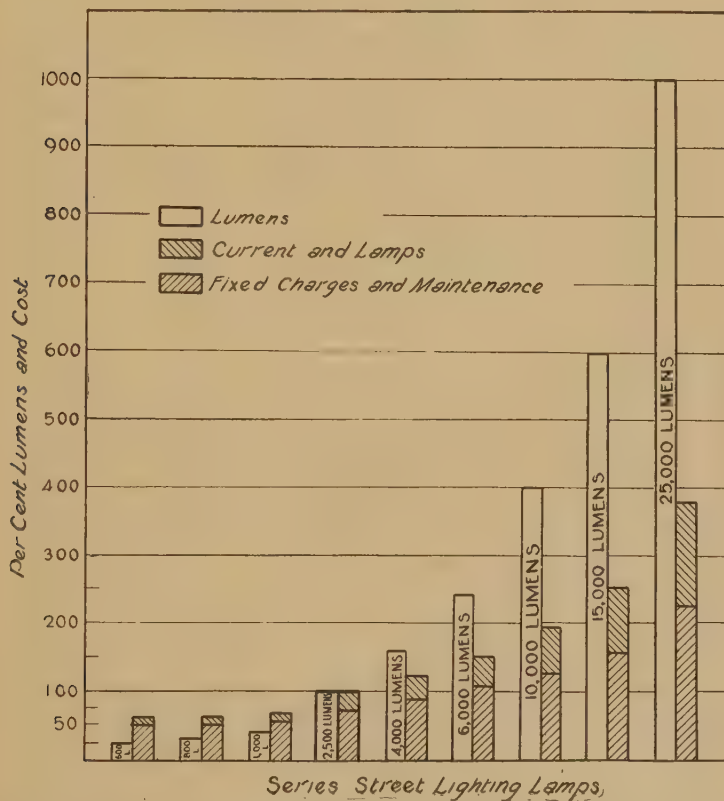


FIG. 134.—The use of larger lamps means an increase in the lumens received per dollar of annual expense.

The table applies directly to series street-lighting systems. The cost computations for a multiple system are less involved and should be followed easily after a study of this table.

TABLE XVII.—ITEMS WHICH ENTER INTO THE TOTAL ANNUAL
OPERATING COST OF INCANDESCENT OR ARC LAMPS FOR
STREET LIGHTING

Electrical data :

1. Rating of lamp, watts.....
2. Loss in individual transformer, watts per lamp.
3. Line loss, watts per lamp.....
4. Watts per lamp at constant-current transformer
(or rectifier set).....
5. Efficiency of constant-current transformer (or
rectifier set).....
6. Watts per lamp measured at 2,300-volt bus....
7. Power factor of system at 2,300-volt bus.....
8. Volt-amperes per lamp at 2,300-volt bus.....

Annual fixed charges :

9. Cost of complete constant-current transformer
outfit, including panel board and arrester (or
complete rectifier outfit), installed.....
10. Number of lamps per outfit.....
11. Cost per lamp of constant-current transformer
outfit (or rectifier outfit).....

Item 1. The wattages of series lamps may be obtained from the lamp manufacturers.

Item 2. The efficiency of the transformers may be obtained from the transformer manufacturers. The range in efficiency is from about 90 to 95 per cent.

Item 3. The line loss depends on the circuit current, size of wire, and length of run. It is usually a small item.

Item 4. This is the sum of items 1, 2, and 3.

Item 5. The efficiency of the constant-current transformer (or rectifier set) may be obtained from the manufacturer.

Item 6. This is item 4 divided by item 5.

Item 7. The power factors of individual pieces of apparatus may be obtained from the manufacturers of the equipment.

Item 8. This is item 6 divided by item 7.

Item 10. The capacity in lamps per outfit may be obtained from the equipment manufacturers.

Item 11. This is item 9 divided by item 10.

TABLE XVII.—*Continued*

12. Cost of Mazda fixture (or arc lamp), installed..
13. Cost of standard, installed.....
14. Total special equipment investment per lamp..
15. Annual fixed charges per lamp on special equipment.....
16. Overhead or underground distribution system—proportionate investment per lamp.....
17. Annual fixed charges per lamp on distribution system.....
18. **Total annual fixed charges per lamp.....**

Annual maintenance :

19. Cost of renewals of Mazda lamps (or electrodes and rectifier tubes).....
20. Cost of replacing broken glassware, globes, and refractors.....
21. Cost of repairs, painting, extra parts and labor on arcs, rectifier sets, Mazda units, etc.....
22. Cost of cleaning (trimming).....
23. Cost of patrolling (if any).....
24. Substation attendance and space rental per lamp.....
25. **Total annual maintenance cost per lamp.....**

Item 14. This is the sum of items 11, 12, and 13.

Item 15. This covers interest, taxes, insurance, and amortization on the special equipment investment per lamp—item 14.

Item 16. The proportionate cost per lamp of the distribution system is obtained by estimating what proportion of the cost of the entire distribution system should be charged against street lighting.

Item 17. This covers interest, taxes, insurance, and amortization on the proportionate investment per lamp in the distribution system—item 16.

Item 18. This is the sum of items 15 and 17.

Items 19 to 23. Estimates of these costs should be based on experience or obtained from other central stations, and in each case should include labor as well as material.

Item 24. Where the constant-current transformers are not located in the substations, an annual charge on the control apparatus which turns the circuits on and off should be substituted for item 24.

Item 25. This is the sum of items 19 to 24, inclusive.

TABLE XVII.—*Continued***Annual energy costs :**

- 26. Generating station and substation investment per kilovolt-ampere.....
- 27. Annual fixed charges on station investment per kilovolt-ampere.....
- 28. Annual fixed charges on station investment per lamp.....
- 29. Energy generating cost per kilowatt-hour.....
- 30. Annual energy generating cost per lamp.....
- 31. Total annual energy generating cost per lamp..

Annual cost summary per lamp :

- 32. Total annual fixed charges per lamp.....
- 33. Total annual maintenance cost per lamp.....
- 34. Total annual energy generating cost per lamp..
- 35. Total annual operating cost per lamp.....

Item 26. Total station investment divided by the total kilovolt-ampere capacity.

Item 27. This covers interest, taxes, insurance, and amortization of the generating station investment per kilovolt-ampere—item 26.

Item 28. This is item 27 multiplied by item 8 and divided by 1,000.

Item 29. In calculating the energy generating cost per kilowatt-hour it must be kept in mind that the fixed charges on the generating-station investment have already been figured as a separate item.

Item 30. This is calculated from items 6 and 29 and from the number of burning hours per year.

Item 31. This is the sum of items 28 and 30.

Item 32. This is item 18.

Item 33. This is item 25.

Item 34. This is item 31.

Item 35. This is the sum of items 32, 33, and 34.

CHAPTER XXI

METHODS OF FINANCING

Impressions to the contrary notwithstanding, it must be accepted as a premise that none of the elaborate methods of financing street lighting eliminates the original cost or any part of it. Someone has to pay the bill. Yet it is true in the purchase of street lighting, as in the purchase of an automobile, that some particular method of financing is often preferable to any other, either because it is more quickly forgotten, or because it happens to fit the purse or the income of the buyer.

Different methods of financing street lighting may therefore be regarded principally as methods of placing the burden on different shoulders. For example, where one part of a city wants a "white-way" system, its cost may be drawn from a general fund or it may be assessed largely against the abutting property. If the rest of the city is poorly lighted, the latter plan is undoubtedly more equitable; on the other hand, if the whole city is well lighted in accordance with a comprehensive plan, there is justice in paying for the "white-way" lighting out of a general fund.

One antiquated method of financing "white-way" lighting—a method which has been found particularly *unsatisfactory*—consists of having the utility make a monthly charge against each occupant of abutting property to cover his share of the cost of the street-lighting system. The contract, of course, terminates automatically whenever the occupant moves away, with the result that many such systems have been operated with a number of lamps dark, or in other cases the utility has kept all the lamps burning at a considerable loss to themselves.

As covered in Chap. XX, street-lighting costs are made up of three different items: fixed charges, maintenance, and electrical energy. The proportion each of these items bears to the whole will vary, of course, depending on the type of system adopted. The items are usually combined by the operating company and the street-lighting charge is made at a flat rate of so much per lamp per year. A flat rate is particularly applicable to

street lighting, as the lamps are of a known wattage and are burned a specified number of hours per year. No metering is required.

With the older type of system—that is, the overhead wire mast-arm construction—the operating company's pole lines are utilized and the standard practice has been for the operating company to bear all installation costs and amortize the investment at a rate sufficient to take care of both physical depreciation and obsolescence. Today, however, practically all business-district lighting is accomplished with ornamental construction, employing underground wiring and ornamental lighting standards. Also, the demand for ornamental lighting is not limited to the business districts but is rapidly spreading to the thoroughfares and residence streets. This type of lighting, of course, costs more to install and the fixed charges are proportionately higher. On the other hand, the ornamental lighting is of material advantage to the district in which it is installed, because it adds to the appearance of the street and consequently is reflected in the increased value of the property. It is undoubtedly this fact which has led a number of the states to pass Lighting Improvement Acts, similar to the laws governing paving, sewers, and other improvements. Under these acts, with the approval of the city authorities and a majority of the property owners affected, the cost of installation and in some cases even the yearly operating costs of an ornamental street-lighting system are assessed against the abutting property. Where the property owners on a particular street or in some section of the city desire street lighting better than that adopted for the city as a whole, the fairness and advantages of the above plan are obvious.

The following methods of financing are practicable and have been used in providing funds for the installation and operation of street-lighting systems:

1. The public utility purchases the equipment; installs it, and operates it, at a flat-rate charge per lamp per year, covering all items. Payments to the utility are met by the city out of its general tax funds.

2. The city issues bonds to cover the cost of the equipment and its installation. The installation is made by the public utility or other contractors, and full payment for same is made by the city upon completion of the job. The utility then makes a flat-rate charge per lamp per year, covering only maintenance and

electrical energy. The bonds are retired from the general tax fund, and the payments to the utility are met by the city from the general tax fund.

3. This method of financing differs from method No. 2 in that the city, instead of retiring the bonds from the general tax fund, makes a special assessment against abutting property to retire the bonds.

4. This method differs from methods No. 2 and No. 3 in that the bonds take care of only a portion of the installation costs—for example, the aboveground costs. The cable and construction costs in this case are defrayed by the public utility, and these costs are amortized in the annual charge per lamp.

5. Another variation of method No. 2 is for the utility to furnish only the energy for the street lamps; the financing is handled by the city, and the maintenance, including the replacing of lamps and the cleaning of globes, is taken care of by a "maintenance company," under contract with the city.

6. The city operates the street lighting and purchases the energy at wholesale from the utility. In this case the investment may be financed as in methods No. 2 or No. 3.

7. A contract covering the entire costs of the lighting system is made between the utility and an incorporated business men's association representing the majority or, preferably, all of the occupants of the abutting property. It is even more satisfactory to have such a contract made with the owners of the abutting property. This method of financing is an outgrowth of the less satisfactory method previously mentioned, wherein the utility contracts with abutting property owners individually. Where the business men do undertake the cost of improved lighting in this way, the city should reimburse them for at least the cost of the street lighting which would otherwise be installed at the expense of the taxpayers at large.

Where the street lighting is supplied by a municipal plant, the methods of financing do not differ in principle from those outlined above. In such cases the municipal plant simply occupies the position of the public utility in these plans.

Of the methods outlined, Nos. 1 and 2 are most commonly employed.

It is an open question whether, in the long run, it is better to have the city or the utility own the special street-lighting equipment. An advantage of city ownership is that municipalities can

generally borrow money at somewhat lower rates than private corporations can obtain. An advantage of utility ownership is that utilities are in the habit of writing off investment on equipment of all kinds at a reasonable annual rate and they are therefore in a position to scrap it in favor of more efficient or better equipment whenever the latter demonstrates its superiority. On the other hand, when a city has paid for something, it is very likely to be kept for a long time, even though its usefulness may be badly impaired, because to scrap it might cause criticism. Utility ownership over a period of years will probably mean that more up-to-date and efficient equipment will be used as it becomes available, and better street lighting will be obtained.

CHAPTER XXII

CONTRACTS AND SPECIFICATIONS¹

A factor that tends greatly toward the satisfactory fulfillment of a street-lighting contract is the spirit of good will existing between the parties to the contract. The creation of such sentiment is advantageous in all business dealings, but is particularly so where lighting contracts are concerned because they often have to be drawn up in a manner more or less flexible as to their interpretation.

It is true that in the past there have been many differences in the interpretation of street-lighting contracts, sometimes resulting in strained relations and even lawsuits. Today such cases are rare, undoubtedly due not only to a more comprehensive knowledge of the illuminants in use and the service to be expected from them, but also in no small measure to the desire on the part of both parties to live up to the spirit as well as to the letter of the contract.

General.—There are some features of street-lighting sales which are different from the sale of any other class of service which the electric service company supplies. For example, street lighting is usually sold in terms of light output over specified periods of time, rather than directly in measured watt-hours of electricity. Such sales are made exclusively to cities and towns in large blocks, rather than in smaller amounts to diversified classes of consumers which include individuals and business corporations.

Negotiations for general franchises and readjustments of rates have in many instances come up for discussion at the same time and have occasionally been factors in the drawing of street-lighting contracts. Undoubtedly, these considerations have in the past necessitated the special handling of street-lighting contracts on such grounds as to necessitate the careful, personal attention of the chief executive of the lighting company.

¹ For the material in this chapter the authors are indebted largely to G. H. STICKNEY, Consulting Illuminating Engineer, Edison Lamp Works and National Lamp Works of the General Electric Co.

With the growth of the system of state utility commissions, the growth of the syndicate systems, and with the standardization of street-lighting equipments, it has been found expedient in many cases to revamp the method of contract, and put the responsibility in the hands of the regular commercial department.

Many of the early contracts were very loosely drawn. The municipal officers had only a vague understanding of the engineering features of the service and, of necessity, depended upon the company to specify and render quality service. While the companies almost invariably handled the responsibility with proper regard to the interest of the municipalities, the situation was not a particularly stable one, since the municipal representatives were so often unable to understand the basis of such large expenditures. Where, due to political changes or otherwise, unfriendly relations arose, the municipal representatives sometimes found themselves too dependent upon the lighting companies for the interpretation of contracts or, on the other hand, attempted to take advantage of loose phraseology. In other cases, the specifications were allowed to lag behind the advance of the art, and so described services which were different from those actually furnished. Even though the latter were superior, the discrepancies provided opportunities for misunderstandings.

This situation led to a number of controversies in the early years of electric lighting, especially with open and enclosed carbon arc lamps. The open-arc lamp had been designated as a 2,000-cp. lamp. More accurate measurements indicated that this was realized only occasionally as a maximum, the mean candlepower of the 9.6-amp. open-arc being on the order of one-third this value. To meet this situation the National Electric Light Association found it desirable to define a 2,000-cp. arc lamp as one which consumed 450 watts. This definition was carried over and applied to the enclosed arc.

One resourceful manager, when confronted with a test showing that his so-called 2,000-cp. arcs emitted only 500 cp., gave the rather ingenious but unscientific explanation, that 500 cp. distributed four ways at a street intersection added up to 2,000.

The situation was not completely taken care of until the progress of the art caused the carbon arcs to be superseded by newer illuminants. Much good will and money were lost through these misunderstandings, which profited neither the companies nor their municipality customers. There are many active men

in the business today who remember the very serious situations that arose and not only hampered street-lighting progress but also affected the entire public relationship.

This ancient history is cited as a reminder of the importance of so specifying street lighting in contracts as to clearly define the service to be performed, avoiding the possibility of ambiguous interpretations.

It is not the purpose of this discussion to consider the features which street-lighting contracts have in common with other types of contracts. Rather, attention is directed to the engineering and other considerations more or less peculiar to street-lighting contracts. Especially it is desired to point out pitfalls and make suggestions in the interest of better understanding and cooperation between the contracting parties.

Term of Contract.—Legal advisers of both utilities and municipalities have expressed themselves in favor of a definite term of contract. The indeterminate contract has too much of a tendency to get out of date. It is sometimes necessary to cancel such a contract to secure a revision of rates, change in equipment, or character of service.

Five years is probably the most common period. From 5 to 10 years is generally to be preferred over a longer or shorter term. Some contracts are for only 1 year, but so short a period does not allow for the writing off of investment items at a reasonable rate.

Anticipating Changes on Renewal of Contracts.—In general it is recommended that the renewal of street-lighting contracts be anticipated well in advance, so as to make sure that the specifications describe the equipment and service to be employed in such a way that the liability of misunderstanding is eliminated.

It is generally better to go to some trouble in clarifying such specifications in advance, rather than to chance the necessity of justifying obsolete provisions under the heat of a misunderstanding. Some companies when facing the necessity for making radical changes in the renewal contract have found it worth while to assume the initiative before the contract has become the subject of political discussion and to arrange to supersede the old contracts 6 months or more before their expiration.

Specifications of Lighting Performance.—Now that street lighting is, in general, being furnished from comparatively few types of illuminants, the performance of which is rather well understood, and concerning which performance data are widely available and

easily obtained, it may be advantageous to use for contract purposes a description of the lighting unit and its conditions of operation. Such a specification is comparatively simple to write and can be verified easily and usually without expensive tests. As pointed out later under Verification Tests, measured illumination performance specifications are expensive to enforce and uncertain of verification.

Equipment Specification.—Where standard types of equipment employing incandescent lamps are used, the following are the features which insure full illumination performance, without recourse to photometric test:

1. Make, type (catalogue number) and size of lighting unit selected, with description of reflector, refractor, and globe equipments.

2. Quality (*e.g.*, Mazda) and rated size of incandescent lamp. **NOTE.**—The size of series lamps is given in lumens, while multiple lamps are rated in watts.

3. Electrical supply (voltage or amperage) of the full amount required by the rating of the incandescent lamps.

4. Maintenance of incandescent lamps, including prompt replacement of broken, burned-out, or defective lamps, lamps showing perceptible blackening or ones which have burned materially more than their rated life (see pages 173 to 177). **NOTE.**—Lamps which have burned much in excess of their rated life generally show low output of light.

5. Maintenance of lighting units in proper adjustment and repair, replacing promptly all broken or defective parts. Painting ornamental posts of metal or wood, or cleaning ornamental posts of concrete.

6. Keeping clean all light-transmitting and reflecting surfaces, such as lamp bulbs, reflectors, refractors, and globes. **NOTE.**—Specifying the number of cleansings per year, instead of equal periods, has the advantage of permitting the company to vary the period, in accordance with variation in burning hours and rate of dirt accumulation for different seasons.

It may be desirable to furnish photometric curves to show the initial performance of the various light-modifying equipments supplied under the contract, but if the above items are complied with, the proper light output is assured without verification tests.

In one contract, a designated city official is given in addition the privilege of challenging a small, specified number of incandescent lamps per year, which he may consider to be giving inadequate light, such lamps being replaced without question. This

has been found to encourage cooperation, and the cost is small, compared with that of adequate testing.

For luminous-arc lamps, a specification similar to that described above can be employed, substituting a quality specification of electrodes for that applying to incandescent lamps, also requiring periodic inspection of voltage adjustment, and the cleansing of globes and reflectors at each trimming.

Sweeping Changes of Incandescent Lamps.—The maintenance of full lumen output is better assured if, in connection with item 4 above, arrangements are made for a sweeping replacement of incandescent lamps after specified hours of burning, say 1,500 hr. This, of course, is likely to add to the number of lamps required in renewal as compared with the practice of replacing individual lamps on burnout or when they may be discovered to be deficient in illumination. On the other hand, the labor cost of replacing lamps in systematic order is so much less than by individual trips that a number of lighting companies have found it economically advantageous to adopt the practice. Other companies are now investigating such a procedure and it is hoped that in the near future there will be data to give a relative idea of the cost of the two methods, in actual operation. The idea is advanced at this time as a possible means of assisting in the elimination of street tests.

Verification Tests.—As already indicated, if the foregoing procedure is followed, it is obvious that there should be no occasion to require illumination or candlepower tests to show fulfillment of contract or as the basis of deduction. So far as incandescent lighting is concerned, a reasonably diligent application of the specifications will insure better maintenance of light output than can be assured by photometric tests.

It is especially recommended that contracts to furnish a measured illumination on the street surface be avoided. There are many objections to such a practice. First: There are factors outside of the control of the lighting company which considerably affect the illumination at various points in the street so that it is impracticable to assure realization of particular measured values. Second: It is evident that, all else being equal, the greater the quantity of light on the street surface the greater the seeing value; on the other hand, the measured minimum, or even average, foot-candle values do not necessarily indicate the relative utility of the illumination, or its cost. Third: Street

illumination measurements are of a much lower order of accuracy than laboratory photometry, and even when taken by skilled observers are not of an order which would make them suitable for the determination of conformity or non-conformity with contract specifications.

If any illumination measurements are to be made—and it is possible that some municipalities will require them—it is preferable that they be in the form of photometric tests of the candle-power or lumen performance of the lamps or lighting units, in one of the relatively few laboratories which have adequate equipment and trained photometrists. Local school laboratories usually fail to qualify for this service, although they may be adequately teaching the theory of light measurement and meeting practical requirements in other classes of photometric testing. In some contracts this feature has been taken care of by requiring that any tests be made by the U. S. Bureau of Standards, The Electrical Testing Laboratories of New York, or a laboratory approved for the purpose by the experts of one of these laboratories.

In one contract in which rather extensive photometric tests may be required upon request of the City's representative, it is also provided that in case the test shows the lighting to be in accordance with the contract, the expense of the test shall be borne by the city. It is understood that though this contract has been in force a number of years no such test has been called for. Such a clause seems equitable and likely to prevent unnecessary testing, as the officials will hesitate to order the test unless they have rather good reason to believe that the illumination is not in accordance with contract requirements.

In deciding whether or not to specify an illumination test, it should be borne in mind that an incandescent lamp is a sealed device. It cannot be adjusted in any way so as to change the power input or light output. If, therefore, Mazda lamps are properly equipped, maintained, and supplied with rated amount of electricity, the chance of their failing to give the proper amount of light is very slight, and certainly insufficient to warrant the expense of verification tests.

A proposed Standard Specification for Street Lighting was printed privately by the British Standards Association, in January, 1927. This proposed standard represents an attempt to evaluate street lighting in terms of the horizontal foot-candles

at a so-called "mid-span point;" *i.e.*, a point midway between lighting units. These specifications are of interest especially for what they may contribute toward guiding the design of street lighting. They do not seem likely to be of use for contractual purposes since they appear to be open to all the objections already recited for the methods of evaluating street illumination and to lack the flexibility required for the wide variety of American conditions.

Question has sometimes been raised as to provision for permitting the municipality's representatives to check the electrical supply. It is of course possible to provide indicating or recording electrical instruments or testing points accessible to municipal officials, and such arrangements have been called for in some contracts.

Penalties and Deductions.—It is reasonable that the charge for service should be made for the period over which it is rendered, and contracts should so specify.

On the other hand, it must be recognized that incandescent lamps fail without notice, and also that occasional emergencies may arise which may put one or more circuits out of service temporarily. There is no practical way of preventing such occurrences. Wherever the company uses proper diligence in making replacements or repairs, the municipality gains nothing ultimately by making deductions for such interruptions, since the company is estimating on such a contract provision will presumably allow liberally for the probability of such interruptions and cover itself in making the rate.

There will undoubtedly be some instances in which deduction clauses will be required by municipal authorities. In such an instance it is urged that reasonable time for correction be allowed before the deduction becomes effective.

Where it is the practice to rely upon the municipal police department to inspect street lighting and report outage, reasonable time for replacement should be allowed after outages are reported to the company, before making deductions.

Improved Equipment.—Street lighting has passed through a period of rapid improvements in equipment. At the present time, equipment appears to be more stabilized. While radical improvements appear less imminent than formerly, it is difficult to predict when improvements may become available, and make for economy or improved lighting. In long-term contracts, it

may be advisable to provide for adoption of such improvements by mutual consent. If the change involves additional cost, the net cost should be borne by the municipality; if it involves an economy in light production the advantage should redound to the municipality.

Extra Charges.—For reasons developing during the life of a contract, there are liable to be demands for construction or service not contemplated at the time of signing. In some contracts, limits are established as to the number of relocations, length of special extensions, or amount of special construction, and all beyond that is charged for at a specified rate, as, for example, labor and material plus 15 per cent. In other instances, all changes requested by the city are subject to an extra charge. In some cases, an installation charge is made against the city for all lamps ordered in during the last year of the contract period.

It is well to state clearly who may authorize such expenditures, and the basis of charge.

Items to Be Considered.—In the preceding, an attempt has been made to point out and discuss some of the important features, in the light of past experience.

The following is a list of important items to be included, or at least considered, in formulating a contract. It is understood that in individual instances some of the items listed will not apply, but it is hoped that the list will have value in suggesting points to be thought of in formulating a contract:

1. General agreement on the part of the company to provide street-lighting services in the streets and other public places of the municipality.

2. General agreement on the part of the municipality to receive and pay for such service.

3. Term and definite limits of contract period.

4. Description of lighting units, lamps, and other equipment—using preferably the ratings of responsible manufacturers, and any necessary limits of quality of performance.

5. Number of lighting units to be provided initially and additions to be made later, particularly those in the last year, to meet the growth of municipality. Limitation of discontinuation of service of equipment, especially if authorized late in contract period.

6. Ownership of equipment. (If any equipment is to be bought or installed by municipality, company approval of material and workmanship.)

7. Schedule of rates for service of different types, spacings, sizes of equipments, and classes of service, number of units, etc.
Lighting schedules and approximate burning hours per year.
Distribution systems (overhead, underground, etc.)
8. Maintenance:
Repairs of equipment.
Replacement of lamps: broken, burned out, blackened
or operated materially beyond rated burning life.
Cleaning and adjustment.
Maintenance of rated electrical supply.
9. Terms of payment:
Provision for arrears.
10. Outage:
Time allowable.
Deductions, if any.
11. Testing if required:
Character; financing; deductions, if any.
12. Extra charges:
Moving units, etc.
Long extensions from existing locations.
13. Substitution of lamps of higher power to meet rising standard of illumination.
Substitution of improved equipment.
14. Renewal of contract or extension of service at expiration of contract.
15. Protection of municipality:
 1. From damages, in event of accident.
 2. From damages, in infringement suits.
16. Use of streets:
Permission and conditions.
Exclusive franchise features.
17. Definitions of any technical and special terms employed in contracts.
18. Provision for arbitration of disputes.

APPENDIX A

EXPLANATION AND DEFINITION OF TERMS

A generation or two ago, when new light sources began to supersede the candle, it was most natural that the illuminating power of these new sources should be expressed in terms of the candle familiar to all. It is probable that the very first comparisons of two light sources were made by setting up the two lamps in the line of vision and gaging them by means of the eye, the natural direction in which to look at the sources being the horizontal.

While there are an infinite number of directions from which the eye might look at a source, the light-giving power in a horizontal direction was made the basis of comparison, and the strength of the light in this direction from a candle made according to certain definite specifications, was arbitrarily chosen as the unit of intensity and called a "candle." The new illuminants, as they were brought out, were rated according to their strength in this same direction and were stated to give so many candles or to be of a certain *candlepower*. Thus when a lamp has a candlepower of 10 (candles), it is meant that its intensity or strength in a horizontal direction is equal to ten times that of one standard candle. This rating of a lamp is made by means of an instrument known as a photometer, a description of which is given in Appendix B.

One essential point to remember in this connection is that the candlepower of a lamp represents the intensity in one direction only. In practice it has been customary for years to rotate the lamp about a vertical axis while the candlepower was being determined and the result was known as the mean, or average, horizontal candlepower.

To carry this conception of candlepower a little further, assume the conditions existing in Fig. 135. In *A*, on the left, is a standard candle and on the right a photometer *P* pointed toward the candle. From what has already been stated, it is obvious that the photometer will indicate 1 cp. In *B*, the same candle is surrounded by a sphere painted a dead black so that all of the rays

striking it are absorbed and cease to be light—in other words, are thrown away, as far as the test is concerned. In this case, the photometer will still indicate 1 candlepower in spite of the fact that a great deal of light has been thrown away. In *C*, a sphere with a much smaller opening is used and, therefore, still more of the light is wasted, but even in this case the photometer will indicate 1 cp. In fact, the reading will be 1 cp. regardless of the size of the opening—that is, regardless of the total quantity of light allowed to be emitted—provided the direct rays from the

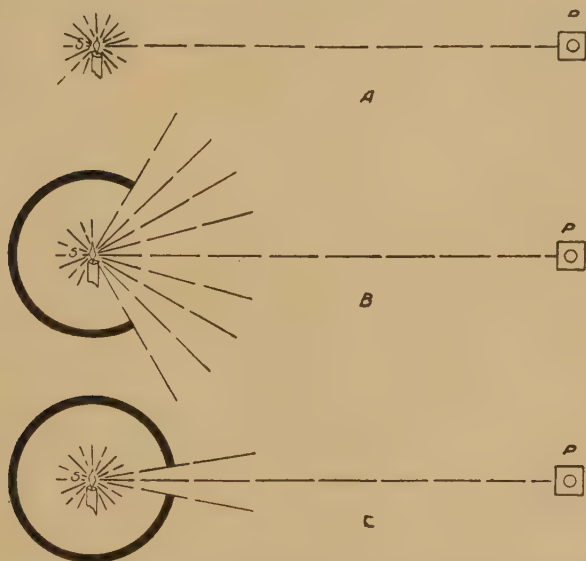


FIG. 135.—The candlepower in the direction of the photometer is not changed by partially surrounding the light source with a non-reflecting surface.

candle to the photometer are not obstructed. This leads to the important conclusion that the candlepower of a source does not necessarily give an indication of the total quantity of light emitted by the source. A candlepower measurement is analogous to the measurement of the depth of a pond at one point—a measurement which may be useful for some purposes but in itself gives no indication of the quantity of water in the pool.

The *mean spherical candlepower* of a lamp is simply the average of all the candlepowers in all directions about the lamp. A source giving 1 cp. in every direction would have a mean spherical candlepower of 1, or if a source gave off various

candlepowers in different directions and if the average of all these candlepowers were 1, the source would have a mean spherical candlepower of 1. The infinite number of directions in which a source ordinarily emits light do not all lie in the same plane, but extend into space on all sides about the source, like the needles of a chestnut burr.



FIG. 136.—The meaning of the different terms in which the candlepower of a light source may be expressed.

The Lumen.—Assume that a source is giving 1 candle in every direction, and that this source is placed at the center of a sphere painted black on the inside and having a radius of 1 ft., as shown in Fig. 137. *OR* represents an opening in the sphere through which some of the light may escape. The quantity of light allowed to escape may be varied by varying the size of the open-

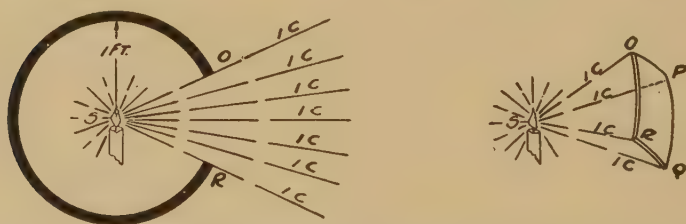


FIG. 137.—The amount of light escaping through the opening *OR*, which has an area of 1 square foot, is called 1 lumen.

ing, with the candlepower of the source and the radius of the sphere remaining fixed. If some definite size of opening at *OR* is assumed, a definite quantity of light which may be used as a unit for measuring quantity will result. The simplest area, or unit, to assume for *OR* is 1 sq. ft. Thus it has been established that the amount of light escaping from an opening of 1 sq. ft. in a black sphere of 1-ft. radius with a source giving 1 candle in every

direction shall be considered the unit of quantity, and it is called a "lumen." The mathematical relations used to fix this unit serve only the same purpose as two scratches on a platinum-iridium bar in the International Bureau of Weights and Measures, the distance between which at a definite temperature is called 1 meter.

If the area of *OR* is doubled, the light escaping will be 2 lumens; if the area of *OR* is made $\frac{1}{4}$ sq. ft., the light escaping will amount to $\frac{1}{4}$ lumen. On the other hand, if there is a source of 2 candles, 2 lumens will be emitted through an opening of 1 sq. ft. in this particular sphere. Since the total surface of the sphere having a radius of 1 ft. is 12.57 sq. ft., removing the sphere entirely, there would be the equivalent of 12.57 openings the size of *OR*; that is, if the candle gives 1 cp. in every direction, with the sphere removed it would give out 12.57 lumens. This means that if the mean spherical candlepower of a lamp is known, multiplying this value by 12.57 gives the number of lumens emitted by the lamp.

It must be remembered that a lumen, in order to be a lumen, need not conform with these exact specifications; it is merely necessary that the quantity of light be equivalent to that prescribed by the definition. A bushel might be defined as the quantity of any commodity contained in a cylindrical measure having a diameter of $18\frac{1}{2}$ in. and a height of 8 in.; however, a bushel of potatoes spread out in the field is just as much a bushel as though the shape of the pile conformed in every respect to the dimensions mentioned.

Candlepower and Lumen Ratings.—Most street illuminants, particularly gas lamps and incandescent electric lamps, were rated in terms of horizontal candlepower. As a basis of comparison this rating was not so inaccurate as might be assumed, for the reason that the candlepower distributions of vertical upright gas mantels and of series incandescent lamps were very similar indeed. In fact, the lumen output of each of these illuminants was almost exactly ten times the horizontal candlepower rating. That is, a 60-cp. gas lamp emitted about 600 lumens, and so did a 60-cp. vacuum incandescent lamp.

This same relation between horizontal candlepower and lumen output does not hold for arc lamps, nor for the newer types of gas-filled incandescent lamps. Therefore, the lumen rating has been generally adopted as being more accurate than the old

horizontal candlepower rating. Contracts which specify lamps of a certain candlepower rating, say, 250, are today considered to call for 2,500-lumen lamps. In the newer and more carefully worded contracts the candlepower rating has been superseded entirely by specifications based on lumen output.

The Foot-candle.—Light is a cause and illumination the effect or result. Both the lumen and the candle are used to measure

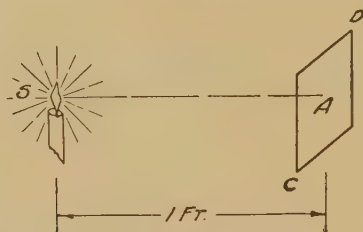


FIG. 138.—The illumination at A is 1 foot-candle.

the cause, these units applying to the light source itself and not to the point where the light is utilized. To measure the illumination on a desk or on the surface of a street, there is a unit called the foot-candle. One foot-candle represents a level of illumination equal to that produced at a point on a plane 1 ft. distant from a source of 1 candle and perpendicular to the light rays at that point. In Fig. 138, if the source *S* gives an intensity of 1 candle

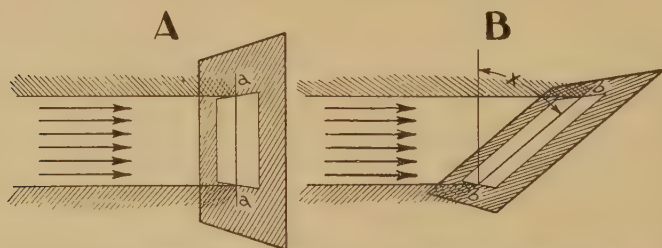


FIG. 139.—The illumination on B is equal to the illumination on A times cosine *X*.

along the line *SA* and if *A* is 1 ft. distant from the source, the level of illumination on the plane *CD* at the point *A* is 1 foot-candle. If, instead of being perpendicular to the beam of light, a plane is tilted at the angle *X*, as shown in Fig. 139, the same amount of light is spread over a greater area. The level of illumination on *B* is to that on *A* inversely as the length *bb* is to *aa*, or as cosine *X*. Thus if $\cos X = 0.7$, and the level of illumination on *A* is 1 foot-candle, the illumination on *B* would be 0.7 foot-candle.

A working idea of a foot-candle of illumination may be obtained by reading a newspaper for 10 min. with the paper held approximately 1 ft. away from a candle. At first the illumination may seem adequate but the observer soon wishes for more light. Incidentally, 1 foot-candle is about the order of illumination which now obtains on the average downtown business streets having "white-way" lighting.

Care should be taken to avoid confusing the level of illumination on a surface, as indicated by the foot-candles, with the appearance as regards brightness of the surface. A gray surface will not appear as bright as a white one lighted to the same level of illumination, for a greater proportion of the light falling upon the gray surface is absorbed and lost. In street lighting, the

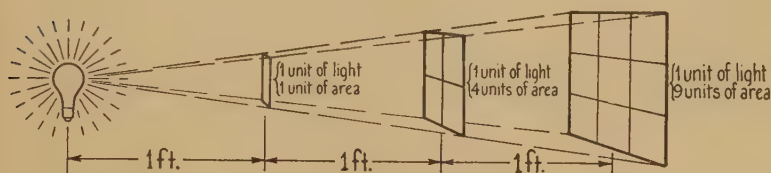


FIG. 140.—The level of illumination on a surface varies inversely as the square of the distance from the light source to the surface.

brightness of a road surface also depends largely upon the angle at which the light strikes it, and whether or not the surface is polished.

Having defined the foot-candle as a unit of level of illumination, the next step is to see how the foot-candles of illumination vary as the candlepower of the source varies. If in Fig. 138, instead of an intensity of 1 candle along the line SA , there is an intensity of 2 candles the illumination at A will be twice as great, and if there is an intensity of 5 candles the illumination at A will be five times as great. Thus, the foot-candles of illumination at a point vary directly with the candlepower of the light source toward that point.

In addition to the effect of the candlepower of the light source, the level of illumination on a surface is influenced by the distance from the source to the surface. With a source of 1 candle as shown in Fig. 140, the level of illumination on A , which is 1 ft. distant, is 1 foot-candle. If, however, the plane A is removed and the same beam of light that formerly was intercepted by A is

allowed to pass on to the plane *B*, 2 ft. away, this same beam of light will have to cover four times the area of *A*, and the average illumination on *B* will be one-fourth as great as that on *A*, or one-fourth of a foot-candle. In the same way, if *B* also is removed and the same beam allowed to fall upon plane *C*, 3 ft. away from the source, it will be spread over an area nine times as great as *A*, and so on. From this it may be concluded that the intensity of illumination is *not* inversely in proportion to the distance, but *inversely as the square of the distance*. This relation is commonly known as the inverse-square law.

Important Relation between Foot-candle and Lumen.—

Referring to Fig. 137 it may be seen that the surface *OPQR* is illuminated at every point to a level of 1 foot-candle, as every point is 1 ft. distant from a source of 1 cp. By definition the quantity of light falling on the surface, *OPQR* is 1 lumen. This gives the important relation that if 1 lumen is so utilized that all of the light is spread over a surface of 1 sq. ft., that surface will be lighted to an average level of 1 foot-candle.

DEFINITIONS OF TERMS¹

Candle, often termed “international candle,” is the unit of luminous intensity maintained by the national laboratories of France, Great Britain, and the United States.

Candlepower is luminous intensity expressed in candles.

Lumen is the unit of luminous flux. It is equal to the flux emitted in a unit solid angle (steradian) by a point source of unit candlepower. A lumen may be popularly defined as the quantity of light intercepted by a surface of 1 sq. ft. every point of which is 1 ft. away from a source of 1 candle.

Foot-candle is a unit of illumination. It is the illumination on a surface 1 sq. ft. in area receiving a flux of 1 lumen uniformly distributed.

Lux is a unit of illumination equal to 1 lumen per square meter; 1 foot-candle is equal to 10.764 lux.

Lambert is a unit of brightness. It is equal to the average brightness of any surface emitting or reflecting 1 lumen per square centimeter. Brightness expressed in candles per square inch may be reduced to lamberts by multiplying by $\pi/6.45$, or 0.487.

¹ Based upon the 1925 *Report* of the Illuminating Engineering Society, Committee on Nomenclature.

Millilambert is 0.001 lambert. As a practical unit for most purposes it is preferable to the lambert.

Foot-lambert is a unit of brightness. It is the average brightness of any surface emitting or reflecting 1 lumen per square foot.

A completely diffuse reflecting surface under an illumination of 1 foot-candle, therefore, has an average brightness of 1 foot-lambert; the average brightness of any surface in foot-lamberts is the product of the illumination in foot-candles by the reflection factor of the surface.

One foot-lambert is equal to 1.076 millilamberts.

Brightness expressed in candles per square inch may be reduced to foot-lamberts by multiplying by 144π , or 452.

Reflection factor of a body is the ratio of the light flux reflected by the body to the flux incident upon it.

Absorption factor of a body is the ratio of the light flux absorbed by the body to the flux incident upon it.

Transmission factor of a body is the ratio of the flux transmitted by the body to the flux incident upon it.

Efficiency of a source is the ratio of the total luminous flux to the total power consumed. In the case of an electric lamp, it is expressed in lumens per watt. In the case of a source depending upon combustion it may be expressed in lumens per thermal unit consumed per unit of time.

Illuminants should be rated upon a lumen basis rather than a candlepower basis.

Performance curve is a curve representing the behavior of a lamp in any particular—candlepower, consumption, etc.—at different periods during its life.

Characteristic curve is a curve expressing a relation between two variable properties of a luminous source, as candlepower and volts, candlepower and watts, candlepower and rate of fuel consumption, etc.

Vertical distribution curve is a polar curve representing luminous intensity of a lamp, or lighting unit, in a plane passing through the axis of the unit and with the unit at the origin. Unless otherwise specified, a vertical distribution curve is assumed to be an average distribution curve, such as may in many cases be obtained by rotating the unit about its axis, and measuring the average intensities at the different elevations. It is recommended that in vertical distribution curves, angles of elevation shall be

counted positively from the nadir as zero, to the zenith as 180 deg. In the case of incandescent lamps, it is assumed that the vertical distribution curve is taken with the base upward.

Horizontal distribution curve is a polar curve representing the luminous intensity of a lamp, or lighting unit, in a plane perpendicular to the axis of the unit, and with the unit at the origin.

Isocandle distribution curve is a series of curves plotted on an appropriate web or form. Each of the series of curves represents a line of equal luminous intensity (candlepower) of the lamp or lighting unit. This type of distribution curve is used for plotting the candlepower curve of asymmetrical (non-symmetrical) distributing units.

Mean horizontal candlepower of a lamp is the average candlepower in the horizontal plane passing through the luminous center of the lamp.

Mean spherical candlepower of a lamp is the average candlepower of a lamp in all directions in space. It is equal to the total lumens of the lamp divided by 4π .

Mean hemispherical candlepower of a lamp is the average candlepower of a lamp in the hemisphere considered, upper or lower. It is equal to the total lumens emitted by the lamp in that hemisphere divided by 2π .

Mean zonal candlepower of a lamp is the average candlepower of a lamp over the given zone.

Spherical reduction factor of a lamp is the ratio of the mean spherical to the mean horizontal candlepower of the lamp.

APPENDIX B

ILLUMINATION MEASUREMENTS AND CALCULATIONS

Photometry.—Photometry is a specialized branch of the science of illumination, which in itself may be made the subject of extended study. The man doing field work in illumination has no need for an intimate knowledge of all the details that enter into this branch of the art. In the following pages, photometers are discussed briefly; for more detailed description of these instruments the reader is referred to standard works on the subject of illumination and photometry.

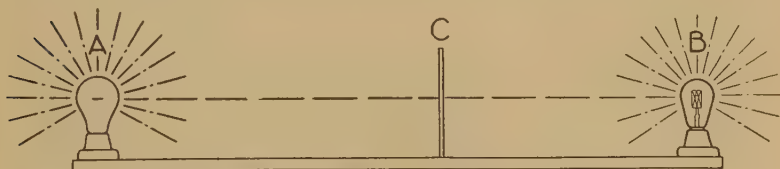


Fig. 141.—The essential parts of a horizontal photometer.

A sketch of the simplest type of photometer is given in Fig. 141. The principal part of this photometer is a vertical paper screen between the lamps to be compared, at the center of which is a grease spot. When the illumination on one side of the screen is greater than that on the other, the spot will on this side appear darker and on the other side lighter than the surrounding paper. By sliding the screen back and forth on the bar, a position can be found where the outlines of the spot will vanish and the spot itself will disappear. When this condition occurs, the illumination on both sides of the screen is the same.

A convenient illustration of this effect may be had by observing a piece of white, watermarked stationery. Ordinarily, one holds paper up to the light to see the watermark, which appears lighter because more light comes through the treated parts. By placing the sheet on a dark surface, the watermark appears dark and may be quite as easily observed. When the paper is held so that the watermark just fades out, the illumination on both sides is approximately the same.

In order that both sides of a photometer screen may be seen simultaneously, mirrors are mounted obliquely behind the screen, to facilitate comparison. In Fig. 142A, it will be noted that the spot as viewed in the right-hand mirror is lighter than its surroundings, which indicates that the left-hand side of the screen is illuminated to a higher intensity than the right. In *B* of Fig. 142, it will be noted that the conditions are reversed—the illumination on the right side of the screen is greater than that on the left. Somewhere between these two positions is a position at which the spot will cease to be visible, as shown in *C* of Fig. 142.

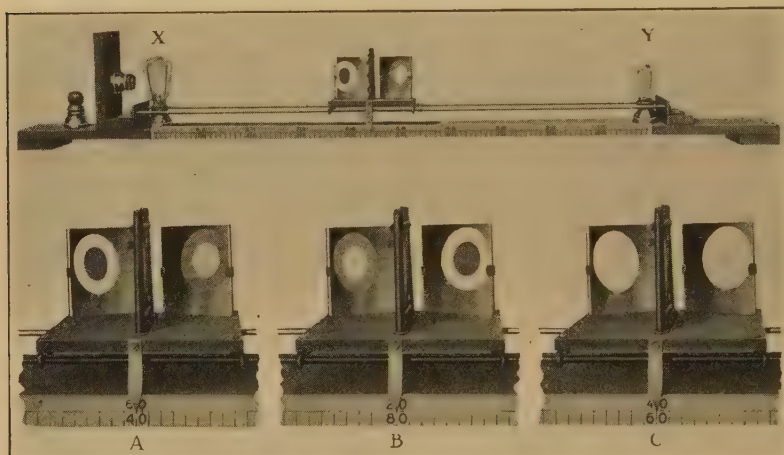


FIG. 142.—Bunsen photometer and screens.

- A. Screen at left of balance point
- B. Screen at right of balance point
- C. Screen at balance point.

From what has been said above, the illumination on both sides of the screen in *C* is the same. Since there is a relation between the amounts of illumination that the two lamps being compared produce, the relation between the candlepowers given, respectively, by lamps *X* and *Y* (Fig. 142) may be determined. The scale of the photometer shows *C* that at a distance of 60 in., the lamp *X* produces an illumination equal to that which the lamp *Y* can produce at a distance of 40 in. At first thought it might seem that *X* must be $\frac{3}{2}$ the candlepower of *Y*, but recalling the inverse square law (p. 202), it is seen that the ratio of the candlepower of *X* to that of *Y* is 3^2 to 2^2 , or 9 to 4. The horizontal candlepower of *X*, therefore, is two and one-fourth times that of *Y*. The general rule, then, is that the candlepowers of two

lamps on a photometer are to each other as the squares of the distances from each to the screen.

Although modern photometers do not use the grease-spot screen, they are the same in principle. They usually employ a Lummer-Brodhun cube, in which two prisms receive light from the sources to be compared, the beams being refracted by the prisms to parts of a pattern. In operation, the position of the comparison lamp is adjusted until all parts of the pattern are

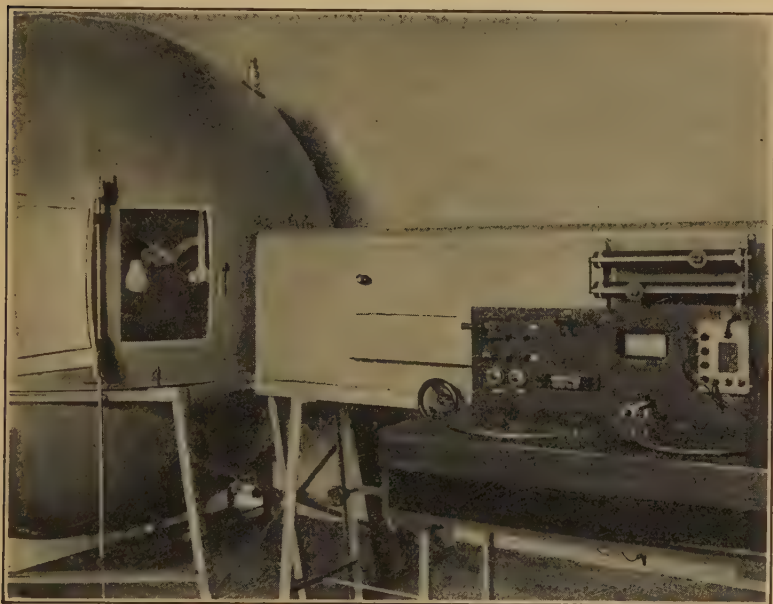


FIG. 143.—Ulbright sphere, used principally for the accurate measurement of the total lumen output of bare incandescent lamps.

uniformly bright. Usually the source to be tested is rotated so as to measure its *average* horizontal candlepower, since the latter may not be exactly uniform on all sides of the lamp.

Another form of photometer known as the "sphere photometer," or Ulbright Sphere, is shown in Fig. 143. In this photometer the lamp to be measured is placed at the center of the sphere (generally large in diameter), whose inner surface is painted flat white. In this sphere is a small window of milk glass, and this window is shielded from the direct rays of the lamp by a small opaque screen. The candlepower of the light emitted by the window is compared with the candlepower of a standard

lamp. The candlepower of the light from the window is directly proportional to the mean spherical candlepower or the total lumen output of the lamp in the sphere,¹ so that multiplying this candlepower by a constant factor determined for the particular sphere gives the total lumen output directly. Thus, at one reading, the mean spherical candlepower or the total lumen output of a lamp can be determined.

Sphere photometry has been reduced to great precision for the testing of incandescent lamps without auxiliary equipment. Where spherical measurements are attempted on lamps in fixtures such as those used in street lighting, the results are, in general, of lower accuracy. The reason for this lower accuracy is that the presence of the fixture in the sphere interferes with the cross-reflection of light and therefore an estimated correction factor must be applied.

Candlepower Distribution Curves.—A candlepower distribution curve is simply a convenient method of showing graphically the candlepower given off at various angles by the particular light source and equipment tested. These curves are of great value in comparing the suitability of different types of lighting equipment, particularly from the standpoints of light distribution and light absorption. Likewise, they give in convenient form the candlepower values necessary in the calculation of street illumination in accordance with the formula on page 218, commonly known as the point-by-point method.

The Dibdin photometer (Fig. 144) and similar equipments are used principally for obtaining candlepower curves of modern lighting equipment. The light from a comparison lamp *H* passes through the baffles *E*, the illumination on the comparison screen being varied by moving the comparison lamp. The control is indicated at *G*. The lighting unit to be measured is mounted at *A* and is revolved by the mechanism at *B*. The operator at the right regulates the position of the lighting unit and the other operator balances on the photometric screen *C* the standard source *H* against the light coming down through the baffles *D* from the unit *A* under test.

Most photometers for obtaining candlepower distribution curves on street-lighting units are like the one in Fig. 144,

¹ That the above condition is true can be proved mathematically, but a discussion of this proof, important as it is in simplifying the operation of determining total light output, is beyond the scope of this book.

operated with the lamp at *A* in the normal, or base-up position. First, the candlepower measurements at the various angles are made on the bare lamp, and then repeated with the lamp inside the fixture or housing. A comparison of the two sets of candlepower values shows the effect of the fixture on the light distribution. Table XVIII shows the result of a test on a 10,000-lumen 20-amp. lamp equipped with a dome refractor and clear rippled

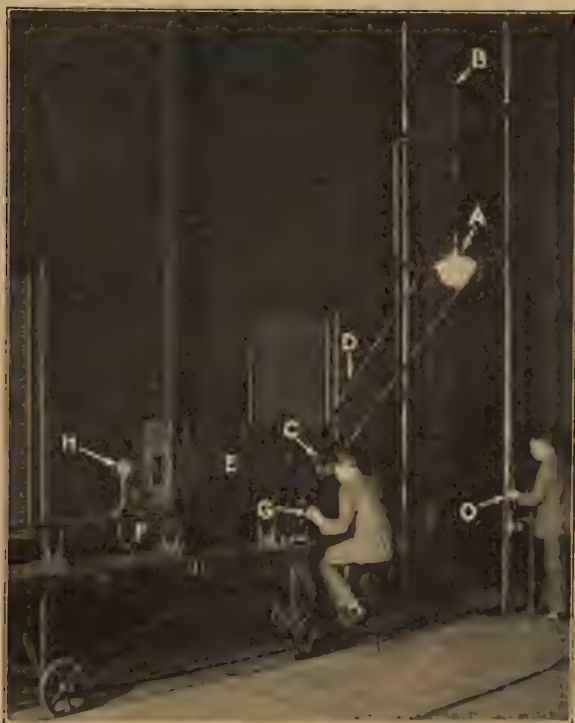


FIG. 144.—Dibdin photometer, used principally for determining the candlepower distribution of lighting equipment.

globe. In this tabulation 0 deg. refers to the reading taken directly beneath the unit. The candlepower in this direction was found to be 350. Likewise 90 deg. represents a measurement taken at the horizontal. In Fig. 145 the distribution curve is shown. It will be noted that at each angle the curve passes through a point which corresponds to the tabulation, that is, the curve cuts the 0 line at 350, passes through 35 deg. at 674, through 65-deg. line at 937, etc. One must not lose sight of the

fact that a distribution curve is a graphical and not a pictorial representation of the light distribution from a source. It is

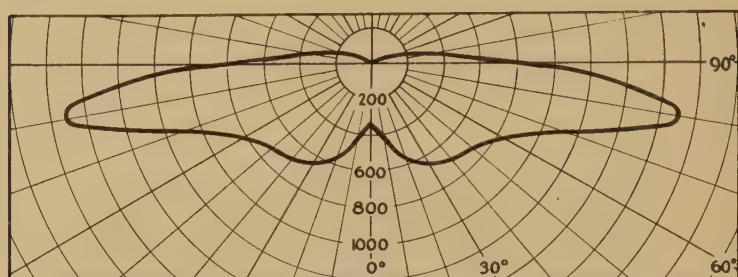


FIG. 145.—Vertical distribution of a clear rippled pendent globe, with dome refractor, inner aluminum reflector, and 10,000-lumen lamp.

simply a convenient engineering method of presenting tabulated data.

TABLE XVIII.—CANDLEPOWER VALUES FROM WHICH THE CURVE IN FIG. 145 IS PLOTTED¹

Angle	Candlepower	Zone	Lumens
0	350		
5	388	0 to 10	37
15	519	0 to 20	184
25	633	0 to 30	477
35	674	0 to 40	900
45	717	0 to 50	1,455
55	775	0 to 60	2,150
65	937	0 to 70	3,080
75	1,437	0 to 80	4,600
85	1,448	0 to 90	6,180
90	850		

The area of a distribution curve is not a criterion of the total light output of a source. The two curves of Fig. 146 apply to two units which give exactly the same total lumens of light.

Another common error in the use of distribution curves is to assume that simply taking the arithmetical average of the candlepowers at different angles, as shown on the distribution curve, will give the mean spherical candlepower of the unit represented. To make the true relation more clear, assume that two men agree to paint the dome of a building in a series of 10-deg.

¹ Values for angles above the horizontal have been omitted from this table.

horizontal stripes and they decide to paint the same number of stripes each. If one started at the top, the other at the bottom, it may be readily seen by Fig. 147 that the amount of work per zone done by the man at 180 deg. would be considerably less than that by the man at 90 deg. Similarly, a high candlepower in a zone near the vertical means fewer lumens than in a zone near the horizontal.

In calculating the flux of light in various zones, it is usually found convenient to calculate for zones of 10 deg., assuming that the candlepower at the center of the zone represents its average candlepower. Table XIX presents the factors by which such candlepower values should be multiplied to give the lumens in each 10-deg. zone.

These factors are proportional to the areas of the zones shown in Fig. 147. In fact, they are the actual square feet in these zones on a sphere of 1-ft. radius. The factors are the same for both hemispheres, but it will be noted that they are in the reverse order.

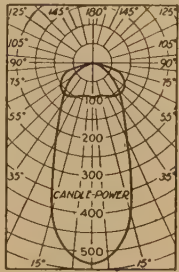


FIG. 146.—These distribution curves, in spite of the difference in their areas, apply to two units whose total lumen outputs are exactly the same.

TABLE XIX.—MULTIPLYING FACTORS TO OBTAIN ZONE LUMENS FROM AVERAGE ZONE CANDLEPOWER

Zone		Multiplying factor
0 to 10°	170 to 180°	0.095
10 to 20°	160 to 170°	0.283
20 to 30°	150 to 160°	0.463
30 to 40°	140 to 150°	0.628
40 to 50°	130 to 140°	0.774
50 to 60°	120 to 130°	0.897
60 to 70°	110 to 120°	0.992
70 to 80°	100 to 110°	1.058
80 to 90°	90 to 100°	1.091

To use these factors with the curve of any lighting unit, the candlepower at 5 deg. is multiplied by the 0- to 10-deg. factor to obtain lumens in the 0- to 10-deg. zone; the candlepower at 15 deg. is multiplied by the 10- to 20-deg. zone factor to obtain the lumens in the 10- to 20-deg. zone, etc. The total lumens for any

large zone is the sum of the lumens thus determined in all of the 10-deg. sections of the zone.

Most street-lighting units give a practically uniform distribution of light about the vertical axis and their light distribution is shown fully by a single chart such as Fig. 145, which is obtained with the unit rotating.

Some of the newer units, usually termed "asymmetric units," are designed to direct more of the light lengthwise of the street than in other directions. These units, therefore, do not give a symmetrical distribution of light about the vertical, and instead

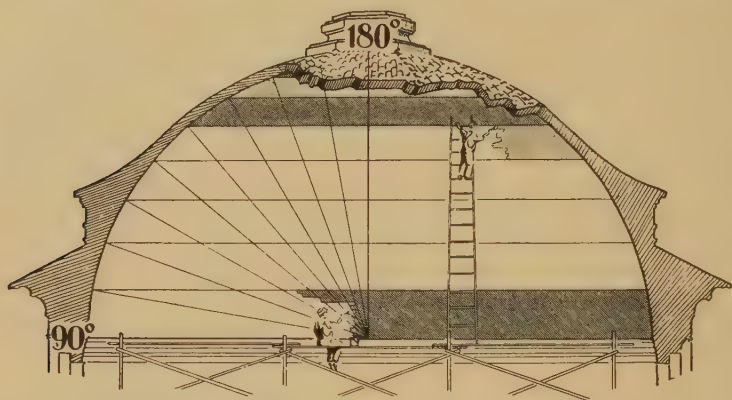
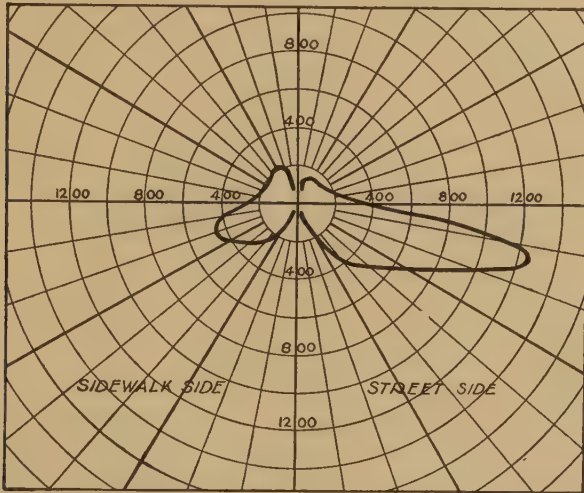


FIG. 147.—The 90 to 100° stripe has a much greater area than the 170 to 180° stripe.

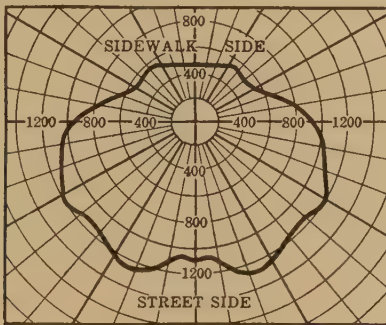
of rotating them to obtain a representative photometric curve, it is necessary to test them stationary and make sets of readings in a number of vertical planes, usually 10 deg. apart. This means that a large number of charts are required to give accurate data as to the performance of the unit. Since such units are usually designed to give the same distribution both up and down the street, however, this reduces the number of charts by half, although the candlepower measurements must be made in the full number of planes to obtain average values in both directions.

In order to give an idea of the light distribution with less laborious testing and plotting, many plans have been tried. One of the most common is to determine the vertical plane which contains the maximum candlepower value and make a series of measurements in this plane similar to Fig. 148 A. It will be observed that with this unit the maximum candlepower is reached

at about 76 deg. from the nadir. To give an idea of the distribution of the unit about a vertical axis, a series of candlepower measurements are then made all around the unit at this angle of 76 deg., and the result plotted as in Fig. 148 *B*. These two



A. Vertical distribution in the plane which contains the maximum candlepower.



B. Lateral distribution in the cone—14 deg. below the horizontal—which contains the maximum candlepower.

FIG. 148.—A method of indicating the light distribution of an asymmetric unit.

curves, of course, give a very incomplete graph of the light distribution of the unit, but in a number of instances the information furnished is sufficient for practical purposes. The danger is that since these curves are plotted to include maximum values, one is likely to receive an overly favorable impression of the effectiveness of units of the asymmetric type.

The isocandle curve (Fig. 149) represents another effort to show graphically the distribution of the same asymmetric unit. The curved lines on the chart indicate points of equal candlepower about the unit: 100, 200, 300 cp., etc. The central vertical axis represents the plane parallel with the street, and the extreme boundaries of the chart, a plane crosswise of the street. In order to plot an isocandle curve it is, of course, necessary to

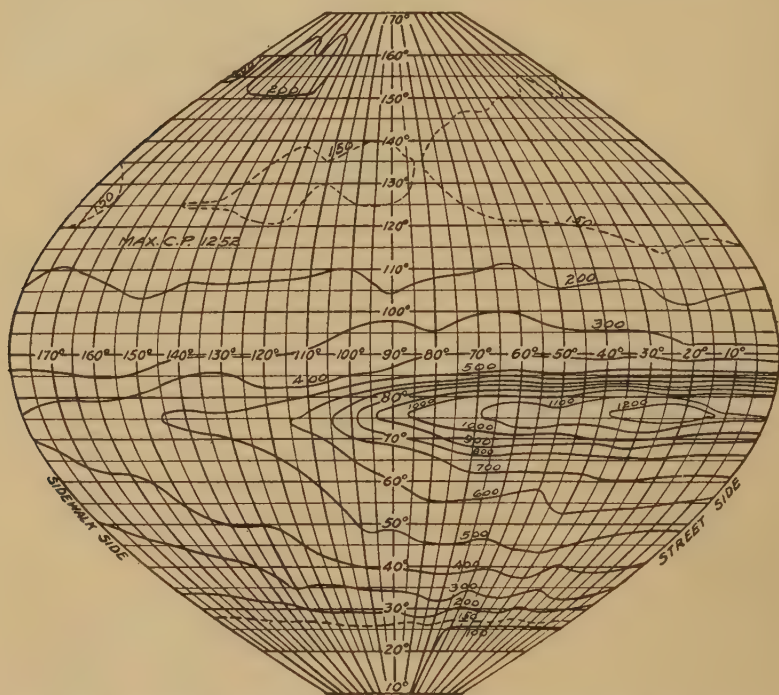


FIG. 149.—Isocandle curves, giving more complete information on the distribution of the unit covered in Fig. 148.

obtain candlepower curves in all the vertical planes at regular intervals (average about 10 deg.) and pick off from these curves the angles at which they cross the 100-cp. line, 200-cp. line, etc., and plot points on the isocandle diagram. For a more complete presentation of isocandle curves, the reader is referred to a paper by Benford and the discussion of the same in the *Illuminating Engineering Society Transactions*, 1926, page 129.

Illumination Measurements.—It will be noted that in measuring the candlepower of light sources, the illumination on opposite

sides of a screen is balanced. Its value is not known. Often, however, it is desired to know the illumination itself—that is, the foot-candle level which is being supplied any given area—rather than the candlepower of the sources which supply the illumination.

By calculating the different foot-candle levels to which one side of the screen of a photometer is illuminated when the distance between the screen and the standard lamp is varied, and then placing the screen so that the illumination to be measured falls upon the opposite side of the screen, the balance of the photometer will give a measurement of the illumination in foot-candles. The difference between photometers used for measuring candlepower and those used for measuring foot-candles are chiefly in form and calibration.

Types of Illumination Meters.—Good portable and semi-portable instruments are now available for use in measuring foot-candles. The one in most common use is the foot-candle meter, shown in Fig. 150. It is very simple to operate, it is so

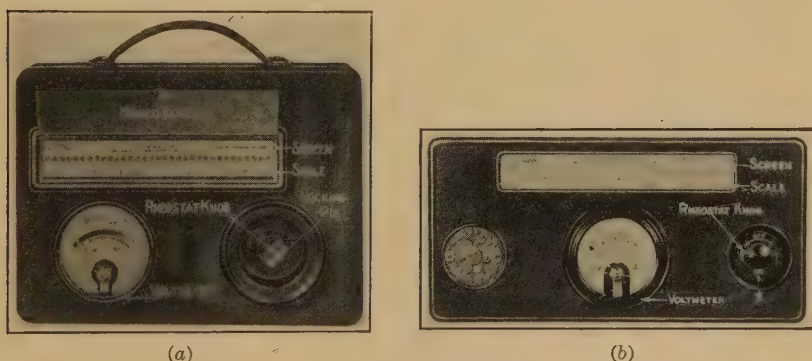


FIG. 150.—The foot-candle meter, for approximate measurement of illumination; *a*, old type; *b*, new type. (Old type used in Fig. 151.)

light that it can easily be carried about, and it is so small that it can be used in very restricted places. In operation, the foot-candle meter is placed upon or adjacent to the surface on which a measurement of the foot-candle level is desired, the voltmeter needle is brought to position, and the reading may be taken. Referring to Fig. 150, a small incandescent lamp, concealed within the box at the right-hand end of the screen and operated from a flash-light battery, illuminates the translucent spots on the screen to a high level at one end and a low level at the other. If the

illumination to be measured falls within the limits of the meter, the spots will appear bright at one end of the scale and dark at the other. At the point where the spots are neither brighter nor darker than the paper scale, where the spot seems to fade into the scale, the illumination from without and within is the same, and the foot-candles of illumination can be read directly. The

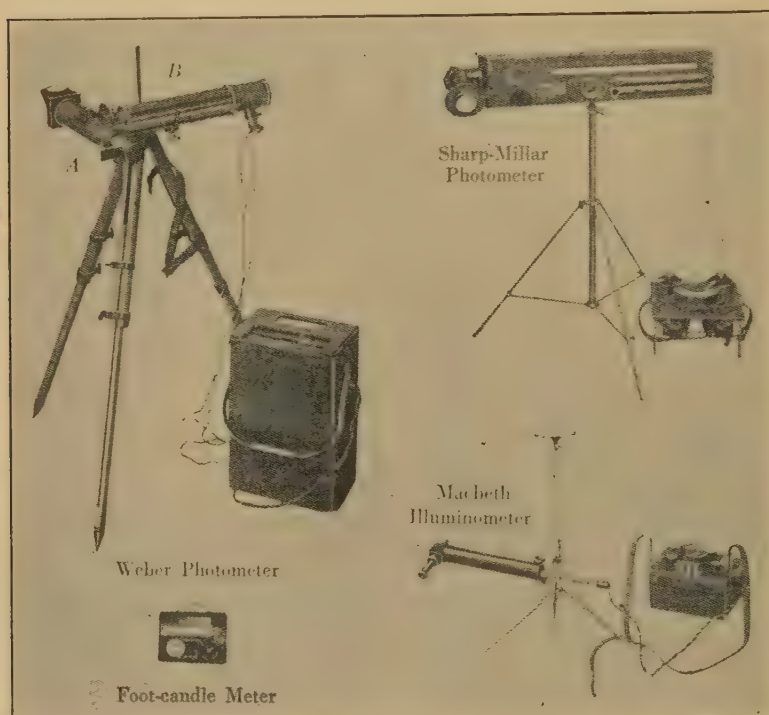


FIG. 151.—Portable photometers, for more accurate measurement of illumination. They are shown in their approximate comparative sizes, including the old type foot-candle meter.

scale is calibrated with the lamp within the box burning at a certain definite voltage; a voltmeter and rheostat enable the operator to obtain this voltage for each reading. "One-tenth" and "double scale" are regularly provided giving a range from 0.1 to 100 foot-candles, and in some cases a $\frac{1}{100}$ scale is used.

The foot-candle meter is intended primarily for approximate measurements of lighting installations. It is not particularly well adapted to the requirements of rigid street-lighting tests.

Fig. 151 shows several types of portable photometers. The Weber photometer, an imported instrument, consists of two tubes at right angles, at the junction of which is a Lummer-Brodhun cube, so arranged that the illumination from the source and standard lamp are observed simultaneously, and balanced by the operator. Tube *A* contains, at the far end, a diffusing glass plate where the light to be measured enters, and at the other, the eye-piece. The comparison standard, at the end of the tube *B*, was formerly a benzine flame but it is generally replaced by a miniature lamp supplied from a storage battery, as shown. The comparison lamp illuminates a milk-glass plate which is moved back and forth in the tube *B*, and carries with it a pointer moving along the scale.

In the Sharp-Millar photometer, the comparison lamp is mounted on a carriage which travels along a track. The carriage is moved by a cord drive manipulated by the knob at the center of the instrument. The scale of the instrument is translucent and is lighted by the comparison lamp; the shadow of a fine cross-wire indicates the reading. At the left end of the box is the optical device, a Lummer-Brodhun prism set. The elbow tube, containing a milk-glass test plate, may be rotated to facilitate taking measurements in any direction.

The Macbeth illuminometer is a more compact instrument and is perhaps the most widely used of the precision type. A rod mounted on a rack-and-pinion gear slides in a metal case. The rod has the comparison lamp at one end and the electrical connections to the milliammeter and battery in the case at the other. The scale is on the front face of the rod. The eye-piece, elbow tube fitted with a mirror, and prism cube are in line at the left end of the instrument. The test plate, as shown, is mounted on a tripod.

All three of these instruments are adapted to making candlepower as well as illumination measurements.

Foot-candles by Point-by-Point Method.—In Appendix A it was shown that, other things being equal, the illumination at a point varies directly as the candlepower of the source and inversely as the square of the distance from the source. This relation, known as the inverse-square law, may be expressed by the following formula:

$$FC = \frac{CP}{D^2}$$

in which FC is the illumination in foot-candles, CP is the candlepower of the source in the direction of the point, and D is the air line distance in feet between the lighting unit and the point on the street surface.

This formula holds provided that the light rays are *perpendicular* to the plane of illumination. In street lighting this is usually not the case and the formula becomes:

$$FC = \frac{CP \times \cos a}{D^2}$$

In which a is the angle between the light ray and the vertical. If the height of the lighting unit above the street is designated by H , then D equals $\frac{H}{\cos a}$ and the formula may then be written

$$FC = \frac{CP \times \cos^3 a}{H^2} \text{ or } Cp \times \frac{\cos^3 a}{H^2}$$

Table XX gives values for $\frac{\cos^3 a}{H^2} \times 1,000$ for various heights (in feet) of the lamps above the street and for various horizontal distances out from the base of the street-lighting post. Where the lamp is not directly above the base of the post, as in the case of bracket-arm units, the horizontal distances in the table should be measured from a spot directly beneath the lamp.

The values in this table represent the horizontal foot-candles which would be on the street if the light source were 1000 cp. In each case, the table also gives the angle a in degrees to assist in taking all the proper candlepower values from the distribution curve of the particular unit to be used. The actual foot-candle value is obtained by multiplying the candlepower value by the value in the table and dividing by 1,000.

Assume that it is desired to know the horizontal foot-candles on the street at a point on the center line of a 56-ft. street midway between two lamps which are spaced 150 ft. apart, on one side of the street only, and located directly above the curb at a height of 20 ft.

From Fig. 152 it will be seen that the horizontal distance from either lamp to the point is $\sqrt{28^2 + 75^2} = 80$. From the table it will be found that where the height is 20 ft. and the horizontal distance 80 ft., the value $\times 1000$ is 0.036, and the angle is 76 deg.

TABLE XX.—VALUES OF THE ANGLE a AND OF $\frac{\cos^3 a}{H^2} \times 1,000^1$

Horizontal distance from unit, feet	Mounting height above pavement, feet									
	12	14	16	18	20	22	24	26	28	30
0	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
10	6.95 40°	5.10 36°	3.89 32°	3.08 29°	2.50 27°	2.06 24°	1.73 23°	1.48 21°	1.27 20°	1.11 18°
20	3.15 59°	2.75 55°	2.38 51°	2.06 48°	1.79 45°	1.56 42°	1.36 40°	1.20 38°	1.07 36°	0.95 34°
30	0.95 68°	0.96 65°	0.95 62°	0.92 59°	0.88 56°	0.84 54°	0.79 51°	0.74 49°	0.69 47°	0.64 45°
40	0.36 73°	0.39 71°	0.41 68°	0.42 66°	0.43 64°	0.43 61°	0.42 59°	0.41 57°	0.40 55°	0.39 53°
50	0.16 77°	0.18 74°	0.20 72°	0.21 70°	0.22 68°	0.23 66°	0.24 64°	0.24 63°	0.24 61°	0.24 59°
60	0.088 79°	0.10 77°	0.11 75°	0.12 73°	0.13 72°	0.13 70°	0.14 68°	0.15 67°	0.15 65°	0.15 63°
70	0.052 80°	0.060 79°	0.067 77°	0.073 76°	0.079 74°	0.084 73°	0.089 71°	0.093 70°	0.097 68°	0.099 67°
80	0.034 81°	0.039 80°	0.043 79°	0.049 77°	0.052 76°	0.056 75°	0.058 73°	0.062 72°	0.065 71°	0.068 70°
90	0.023 82°	0.026 81°	0.030 80°	0.033 79°	0.036 77°	0.039 76°	0.041 75°	0.044 74°	0.046 73°	0.048 72°
100	0.016 83°	0.019 82°	0.021 81°	0.023 80°	0.026 79°	0.028 78°	0.030 77°	0.032 75°	0.033 74°	0.035 73°
120	0.012 84°	0.014 83°	0.015 82°	0.017 81°	0.019 81°	0.021 80°	0.022 79°	0.024 78°	0.025 77°	0.026 76°
140	0.0068 85°	0.0079 84°	0.0090 83°	0.010 83°	0.011 82°	0.012 81°	0.013 80°	0.014 79°	0.015 79°	0.016 78°
160	0.0043 86°	0.0050 85°	0.0057 84°	0.0064 84°	0.0071 83°	0.0077 82°	0.0084 81°	0.0090 81°	0.0096 80°	0.010 79°
180	0.0029 86°	0.0034 86°	0.0038 85°	0.0043 84°	0.0048 84°	0.0052 83°	0.0057 82°	0.0061 82°	0.0065 81°	0.0070 80°
200	0.0020 87°	0.0024 86°	0.0027 85°	0.0030 85°	0.0034 84°	0.0037 84°	0.0040 83°	0.0043 82°	0.0046 82°	0.0050 81°
220	0.0015 87°	0.0017 86°	0.0020 86°	0.0022 85°	0.0025 85°	0.0027 84°	0.0029 84°	0.0032 83°	0.0034 83°	0.0036 82°
240	0.0011 87°	0.0013 87°	0.0015 86°	0.0017 86°	0.0019 85°	0.0020 85°	0.0022 84°	0.0024 84°	0.0026 83°	0.0027 83°
260	0.00087 87°	0.0010 87°	0.0012 86°	0.0013 86°	0.0014 86°	0.0016 85°	0.0017 85°	0.0018 84°	0.0020 84°	0.0021 83°
280	0.00068 88°	0.00079 87°	0.00090 87°	0.0010 86°	0.0011 86°	0.0012 86°	0.0013 85°	0.0015 85°	0.0016 84°	0.0017 84°
300	0.00054 88°	0.00064 87°	0.00072 87°	0.00082 86°	0.00090 86°	0.00099 85°	0.0011 85°	0.0012 85°	0.0013 85°	0.0013 84°
	0.00044	0.00052	0.00059	0.00066	0.00074	0.00081	0.00088	0.00095	0.0010	0.0011

¹ The angle a is indicated in Fig. 152. The values of $\frac{\cos^3 a}{H^2} \times 1,000$ are the horizontal foot-candles at various points on the street for a light source of 1,000 cp. toward those points.

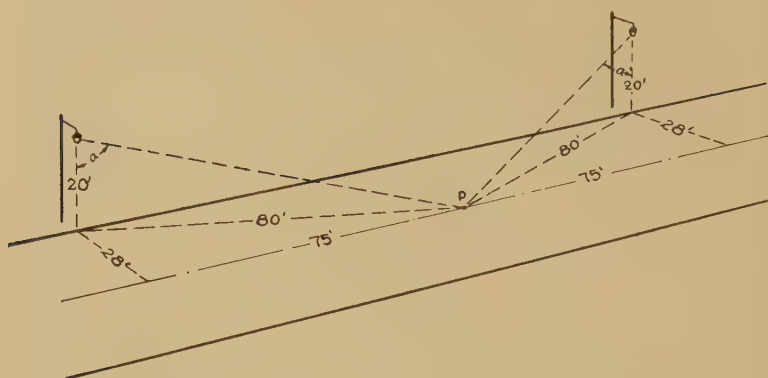


FIG. 152.—The example of the point-by-point method of calculating horizontal foot-candles, as given on page 217, refers to this street.

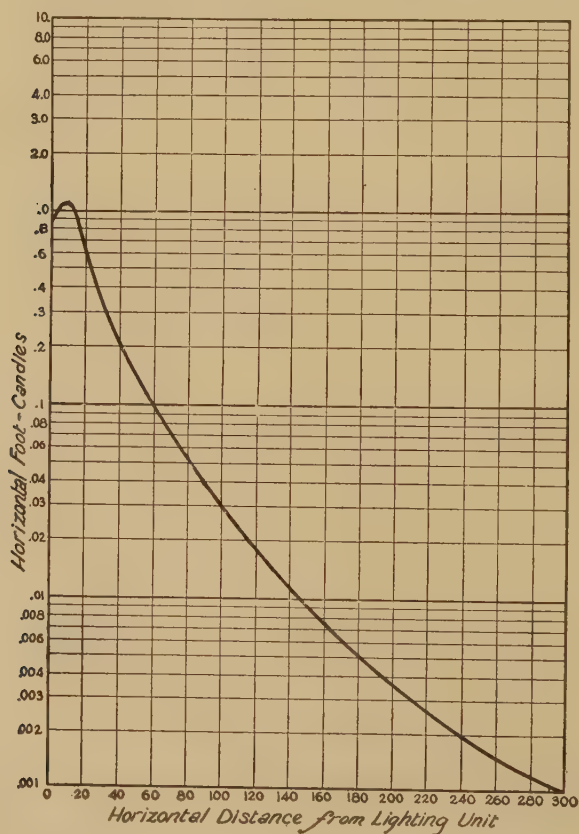


FIG. 153.—“Foot-candle distance” curve, for a 20-ft. mounting height and the light distribution in Fig. 145.

For the unit whose distribution curve is given in Fig. 145 on page 210, it will be seen that the candlepower at 76 deg. is approximately 1,530. The foot-candle value from one lamp is, therefore,

$$FC = \frac{1,530 \times 0.036}{1,000} = 0.055$$

Since there are two lamps, the total illumination is 0.11. If the lamps were not equally distant from the point, obviously, it would be necessary to calculate for them separately, and in some cases the slight illumination from more distant lamps must also be obtained and taken into account.

If it is desired to calculate the foot-candle values at many points *for a given light source and mounting height*, much time will be saved by plotting a "foot-candle distance" curve for the unit in question, as shown in Fig. 153. Likewise, the distances from the base of the post to various points on the streets may well be determined graphically from a scale drawing of the street.

The average illumination on the street surface may be determined by dividing a representative section of the street into 8- or 10-ft. squares and calculating the illumination at the center of each square.

Horizontal Illumination by Zonal-flux Method.—For lighting units which have a symmetrical distribution of light about a vertical axis, the zonal-flux method of calculating the average horizontal illumination on the street is far less laborious than the point-by-point method just outlined. The zonal-flux method is based on the fact that, with any given unit which has a symmetrical distribution of light, a certain proportion of the total lumens given off by the unit will fall on the street. This proportion depends on the street width and the location, mounting height, and vertical light distribution of the unit, as sketched in Fig. 154. The curves in Fig. 155 show the percentage of the total lumens in each 10-deg. zone which will fall on the street, for any given ratio of street width to mounting height of lighting unit. From these data and from the distribution curve of the unit, which gives the lumens emitted in the various 10-deg. zones, the total number of lumens falling on the street may be calculated. Dividing this number by the street area in square feet per lighting unit gives the average initial horizontal illumination in foot-candles.

As an example of zonal flux calculation, suppose it is desired to know the average initial horizontal foot-candles on the pave-

ment area of a 60-ft. street. The lighting units, mounted on brackets, are 20 ft. above the pavement and overhang the street 10 ft. There is one unit for every 100 lin. ft. of street. The horizontal light distribution of the units is symmetrical, and their vertical distribution and zonal lumens are as shown in Fig. 145.

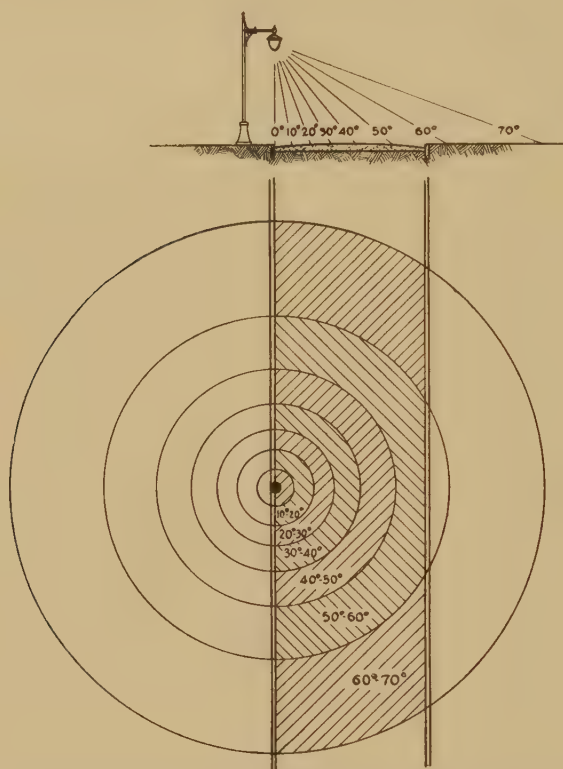


FIG. 154.—For a unit with a symmetrical distribution, the number of lumens falling on the street depends on the street width and the mounting height, location, and vertical distribution of the unit.

The pavement width is 60 ft. but as the units overhang the street 10 ft. the solution involves breaking the street into two strips—one strip 50 ft. wide and the other 10 ft. wide—and finding the sum of the lumens which fall on these two strips.

First taking the 50-ft. strip, the ratio of street width to mounting height is 50 to 20, or 2.5. With this 2.5 ratio, from the curves in Fig. 155 it is found that up to the 50- to 60-deg. zone all of the light on one side of the lamp—that is, 50 per cent of the

total zonal lumens—falls on the street, in the 60- to 70-deg. zone but 48.5 per cent, in the 70- to 80-deg. zone 24 per cent, and in the 80- to 90-deg. zone 7 per cent. Applying these percentages to the

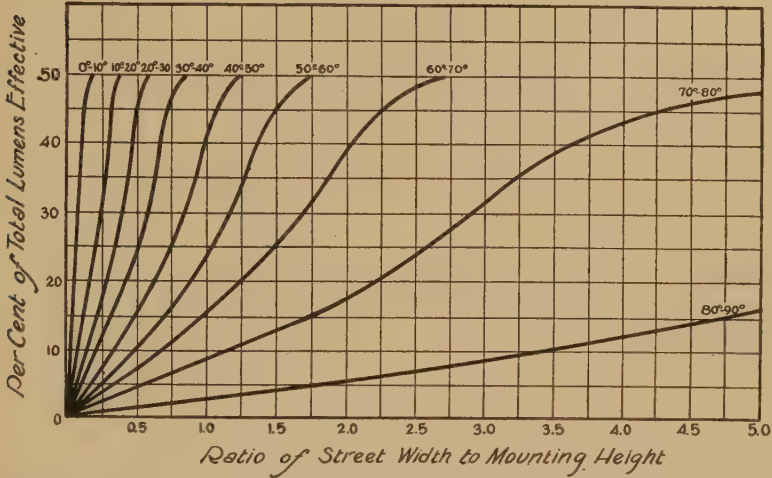


FIG. 155.—Based on the sketch in Fig. 154, these curves show what percentage of the total lumens in each 10-deg. zone fall on the street.

respective zonal lumens, as given in Fig. 145, and making a summation, it is found that a total of 1,999 lumens falls in the 50-ft. strip (see Table XXI).

TABLE XXI.—AN EXAMPLE OF ZONAL-FLUX CALCULATION

Zone	Zone, lumens	Effective lumens 50-ft. strip		Effective lumens 10-ft. strip	
		Percentage	Lumens	Percentage	Lumens
0 to 10°	37	50	18	50	18
10 to 20°	147	50	73	50	73
20 to 30°	293	50	146	45.5	133
30 to 40°	423	50	211	24.5	104
40 to 50°	555	50	277	16	89
50 to 60°	695	50	347	11	76
60 to 70°	930	48.5	451	7.5	70
70 to 80°	1,520	24	365	4	61
80 to 90°	1,580	7	111	1.5	24
	6,180		1,999		648

Then taking the 10-ft. strip, the ratio of street width to mounting height is 10 to 20, or 0.5. For a ratio of 0.5 the curves in Fig. 155 show that 50 per cent of the lumens in the 0- to 10-deg. zone and the 10- to 20-deg. zone fall in the 10-ft. strip, but only 45 per cent in the 20- to 30-deg. zone, etc. Reducing the percentages to lumens and adding, it is found that a total of 648 lumens falls in the 10-ft. strip.

Adding the 1,999 lumens in the 50-ft. strip to the 648 lumens in the 10-ft. strip gives a total of 2,647 lumens effective on the street from curb to curb. Since there is one street lamp for each 100 lin. ft. of street and the pavement width is 60 ft., the pavement area per street lamp is 6,000 sq. ft. Dividing the total lumens, 2,647, by 6,000 sq. ft. gives 0.44 foot-candles as the average initial horizontal illumination on the pavement surface.

The above solution holds for a system in which there is one unit per 100 lin. ft. of street, regardless of whether the units are staggered or all on one side of the street. With units spaced 100 ft. apart on both sides of the street, the lumens will, of course, be doubled, and if two-light units are used on both sides of the street the lumens will be quadrupled.

The zonal-flux method may also be used to calculate the average horizontal illumination over the entire street from property line to property line. To make this calculation for the same street, assuming a distance of 90 ft. from property line to property line, the two strips are 65 ft. wide and 25 ft. wide, instead of 50 ft. and 10 ft. where the pavement alone is considered.

APPENDIX C

PRINCIPLES OF STREET LIGHTING¹

The Illuminating Engineering Society's Committee on Street Lighting was organized in March, 1925. At its first meeting the Committee reached the conclusion that it would be desirable, if practicable, to formulate a statement of such principles of street lighting as might find acceptance on the part of its members. While engaged upon this task, the Committee undertook at its first meeting to list the elements which make for effectiveness in street lighting and to ascertain by assignment of numerical weights what differences of opinion were entertained by the Committee members on these fundamentals. The differences proved to be so great that the formulation of a statement of principles of street lighting was deferred.

During the year 1927, however, the Committee did formulate certain statements of Principles of Street Lighting which it adopted tentatively and which it offered for constructive criticism. The Committee expects to engage in a revision of these statements in the future and invites all who may be interested to contribute their views for consideration in connection therewith. Accordingly the statement of principles is presented here.

The major purposes of street lighting are:

1. *To promote safety and convenience in the streets at night through adequate visibility.*
2. *To enhance the community value of the street.*

Street lighting thus serves utilitarian purposes, and like other utilities, it serves its purpose best if it is artistically satisfying. Best visibility is usually compatible with most pleasing appearance. A street lighting system cannot be artistic unless it provides good visibility.

¹ Taken from a *Report* presented before the Twenty-first Annual Convention of the I.E.S., Chicago, Ill., Oct. 11-14, 1927.

"The beautiful rests on the foundation of the necessary." Emerson.

Thus arises the further purpose:

3. *To accomplish the illumination of streets with the greatest practicable promotion of the aesthetic qualities of the street and of the street lighting equipment.*

Principles of Street Lighting.—For the purposes of this statement the following selected definition is proposed:

Principle.—A generally accepted fundamental proposition underlying good practice.

Principles of street lighting may be comprehended under the following heads:

Street conditions.

Visibility.

Appearance.

Economics.

These may be subdivided as follows:

100—*Street Conditions*

110—Classification, design and dimensions

120—Street surface

130—Buildings

131—Proximity to street

132—Class

140—Trees

150—Traffic

151—Vehicular

152—Pedestrian

200—*Visibility*

210—Lamp locations

211—Mounting height

212—Spacing

213—Transverse location

220—Characteristics of lighting equipments

221—Lamp rating

222—Candlepower distribution

223—Lumen output

224—Brightness

225—Color of light

226—Steadiness of light

230—Characteristics of illumination

231—Intensities upon various planes

232—Uniformity

- 233—Direction of incident light
- 234—Pavement brightness
- 235—Building front brightness
- 236—Shadows
- 240—Glare
- 300—*Appearance*
 - 310—Of lighting equipment
 - 311—By day
 - 312—By night
 - 320—Of street as affected by lighting equipment
 - 321—By day
 - 322—By night
- 400—*Economics*
 - 410—Installation
 - 420—Operation

NOTE.—It is important that no statement of subordinate nature should be considered apart from that part of the context to which it is subordinate.

100—So far as is compatible with other requirements, conditions of the streets and surroundings should be made promotive of good visibility.

110—For lighting purposes streets may be classified conveniently according to their type and traffic function.

A satisfactory classification follows:

- Primary business streets
- Secondary business streets
- Heavy traffic thoroughfares
- Medium traffic thoroughfares
- Light traffic thoroughfares
- Residence streets
- Alleys
- Highways

120—The street surface should be of as favorable light-reflecting quality as practicable (see 213.1). From the illumination standpoint light colored pavements are preferable. When not light colored a specular (shiny) surface is preferable to a dull (mat) surface. The curb should contrast with the pavement or with the abutting parkway or sidewalk.

121.1—A rough listing of pavements with respect to their light-reflecting qualities will place concrete at the head of the list and oil bound

macadam at the bottom of the list. Other generally used materials range between these two.

130—For business streets, building fronts having good light-reflecting qualities improve visibility and appearance at night.

140—So far as is compatible with other requirements, obstruction of light by trees should be minimized.

141.1—Trees should be near the property line rather than between the sidewalk and the curb.

141.2—Trees should be trimmed to a reasonable extent to favor the lighting.

141.3—Varieties of trees which tend to be free from low growing branches are preferable.

141.4—Responsibility for all street trees should be lodged with a designated competent authority.

150—The proper amount of illumination to supply for any street depends to a large degree upon the density of traffic during hours of operation of the street lighting system.

200—**Promotion of good visibility is the most important object of street lighting.**

NOTE.—Visibility is commonly achieved in one or more of the following ways:

- (1) Diffuse reflection of light from the surface of an object on the street. This is the major factor when illumination intensities approach the upper limits of modern street lighting practice.
- (2) An object is readily discernible when more bright or less bright than its surroundings. Silhouette of an object against an illuminated background is commonly a major factor in vision when, as in the case of concrete pavements, the brightness of the street surface is greater than that of objects on it. Other pavements, notably asphalt, polished by automobile traffic, take on a sheen thereby promoting vision by silhouette from distant lamps.
- (3) A shadow often reveals the presence of an object.
- (4) Glint from polished or wet surface of an object often reveals its presence.

- 201—The effectiveness of street illumination is measured by ability to see rather than by illumination intensity or silhouette or any other single factor.
- 202—Visibility requirements of all users of the street should be met, including those of vehicle drivers and passengers, pedestrians and occupants of property abutting on the street.
- 203—Conspicuity of pedestrians at street intersections, on sidewalks and on contiguous property should be promoted.
- 210—The advantageous location of street lamps is a very important factor in promoting good visibility.
- 211—Lamp mounting height should be selected with reference to weighted requirements for good visibility, good appearance and economy of installation and operation.
 - 211.1—Generally speaking, and within practicable limits, effectiveness is improved by increasing mounting heights beyond present practice (see 240).
 - 211.2—With present types of lighting equipment 15 ft. is the minimum mounting height for effective illumination. Only in case of extremely heavy forestation should any exception to this rule be considered.
 - 211.3—Where spacings are 250 feet or more, the mounting height should not be less than 20 feet.
 - 211.4—6,000 to 15,000-lumen lamps in pendent equipment on thoroughfares should be mounted at least 20 feet high.
- 212—Lamp spacings should be selected by weighted requirements of good visibility, good appearance and economy of installation and operation.
 - 212.1—Street intersections should be more brilliantly lighted than other portions of streets.
- 213—Transverse location of lamps with reference to the curb line should be determined by the weighted requirements of good visibility, good appearance and economy of installation and operation.

- 213.1—In proportion as the street surface is specular, placement of lamps well out over the roadway tends to enhance effectiveness, provided they are not unduly glaring.
- 213.2—In a thoroughfare or residence street, pendent equipment out over the roadway usually is more effective in promoting visibility than is upright equipment.
- 213.3—For broad thoroughfares effectiveness is promoted by having lamps on both sides of the street.
- 213.4—If practicable, lamps on curves should be placed on the outside of the curve. On curved roadways, lamps should indicate roadway direction. A staggered system on such streets is generally undesirable.
- 213.5—Adequate illumination should be provided especially at dead ends of streets or at offset streets.
- 220—Illuminants should possess characteristics desirable for street lighting service, including reliability of operation, good candlepower maintenance, good economy, *i.e.*, high ratio of useful light output to cost of operation and maintenance, reasonable steadiness, desirable hue of light, etc.
- 221.1—There are no conditions of street lighting prevailing in the United States which justify the use of smaller than 1,000-lumen lamps. The 2,500-lumen lamp is the smallest size which may be used with good economy.
- 222—It is good practice to direct a relatively large percentage of the light toward the street.
- 222.1—Redirecting equipment should generally be employed in residence streets and thoroughfares.
- 223—Accessories should absorb as little light as practicable.
- 224—Powerful light sources which are small and brilliant should be equipped with accessories which avoid undue glare, or should be removed from the ordinary field of view sufficiently to accomplish this purpose (see 240).

- 225—The color of light from street lamps should be favorable to best visibility and appearance.
- 226—Light from street lamps should not be so unsteady as to interfere with best visibility or appearance.
- 230—Street illumination should promote visibility and good appearance of the street.
- 231.1—Sufficient light should be distributed on abutting property to make it possible to see persons or objects in front of houses and, so far as practicable, between houses.
- 231.2—For thoroughfares, average horizontal illumination¹ of at least 0.2 foot-candle, attainable with available illuminants in good practice, at an expenditure of about 40 lumens per linear foot^{1,2} is to be considered a minimum. For streets exceeding 80 feet in width more light is required; under dense traffic conditions much higher illumination is desirable.
- 231.3—For residence streets average horizontal illumination of at least 0.05 foot-candle should be provided, with higher values recommended. In good practice this minimum can be obtained with an expenditure of about 10 lumens per linear foot.
- 232—While uniformity of illumination intensity is desirable, departure therefrom within reasonable limits, particularly in the direction of higher intensity, is not objectionable.
- Dark spaces between lamps should be avoided.

¹ The term "lumens per linear foot" and like expressions are measures of light output for street lighting. Such a term is analogous to "watts per square foot" employed in interior lighting. It does not take into account the proportion of light which reaches the street and is but a rough and incomplete index of the grade of illumination.

The term "average horizontal foot-candles" because it does indicate the light delivered upon the street is a somewhat more complete index of the grade of illumination but is not a complete measure since it does not take into account several important factors, notably glare, brightness, and distribution of light

² Where lumens or watts per linear foot are shown without specification a street of not more than 80 feet between property lines is contemplated.

- 232.1—A spacing mounting-height ratio of approximately 8 to 1 usually provides a satisfactory approach to uniformity of illumination.
- 233—Illumination in which the major component of the light is incident from one direction promotes contrasts and shadows. Within reasonable limits, and especially at low levels of illumination, such lighting improves visibility in streets at night.
- 234—At recommended or higher levels of illumination uniformity of street surface brightness is desirable.
- 236—Shadows in street lighting are unlikely to aid visibility. Lamps should be so located as to minimize objectionable shadows and to direct them least objectionably.
- 236.1—Shadows of tree trunks are least objectionable when units are placed on the tree lines. (However, this statement is not a recommendation for such location in preference to the recommendation of 213.1 and 213.2.)
- 240—Glare as experienced in the street, on the sidewalk and from neighboring buildings interferes with vision, is annoying or even offensive. It also introduces hazard and detracts from the appearance of lighting equipment and of the street.
- Glare should be minimized.
- Other things being equal, the effects of glare are diminished:
- (a) As the candlepower and brightness in the direction of the observer are reduced.
 - (b) As the lamps are removed from the center of the field of view. This is accomplished most effectively by increasing the mounting height.
 - (c) As contrasts are reduced, as by illuminating surroundings (building fronts, etc.).

It is possible to confine glare within unobjectionable limits.

The use of diffusing globes has no measurable effect on that part of glare which has been called "blinding effect," or decreased ability to see when at attention. However, such equipment is effective in reducing ocular discomfort and in promoting good appearance. The effectiveness of street lighting is greatly dimin-

ished by glaring headlights. Headlight beams which conform with the specifications of the Illuminating Engineering Society are less objectionable. "Depressed beams" are even less objectionable.

300—The appearance of street-lighting equipment should reflect good taste and sense of propriety. While congruity with the character of the street, its environs and use is desirable, equipment should deviate in the direction of better taste than is displayed in a low grade or unaesthetic street. Simplicity, dignity, and grace rarely displease and are never out of place as a visible expression of a civic service.

310—Lamp supports and equipments should harmonize architecturally and should be in keeping with the environment.

The standard which serves as a lamp support should be in good proportion and inconspicuous, blending harmoniously with the surrounding architecture. Uniformity of appearance of equipment is desirable. So far as is compatible with good visibility, the lighting equipment should be inconspicuous. It is desirable to avoid any size or multiplicity of equipment which may achieve undue prominence in the appearance of the street.

320—From the aesthetic standpoint street lamp posts and equipment should be selected primarily with reference to the appearance of the street and secondarily with reference to the appearance of the lighting equipment by itself.

321.1—Underground service is desirable for improved streets where practicable. Where curb and gutter have been generally installed, underground service will usually be found best practice.

322—Good visibility having been obtained, it is important to achieve the most pleasing appearance and the best practicable general effect.

400—The installation and operation of a street-lighting system should be accomplished with all practicable economy in order to secure to the public the utmost of lighting effectiveness, with due regard to appearance, which can be had for the expenditure involved.

- 401.1—Expenditure, purely for aesthetic reasons, is hardly justifiable until good visibility has been secured.
- 410—Street lighting systems should be installed with due regard to their future improvement and extension.
 - 411.1—Where curb lines of unimproved streets have not been established, street lamps should be supplied from overhead circuits.
 - 411.2—When streets are being improved, crossovers should be installed at reasonable intervals.
 - 412.1—Where overhead service is necessary, existing poles should be utilized when practicable.
 - 413.1—Post structures should be set back from the curb to avoid damage but should be easily replaceable if damaged.
- 420—Reliability of service, with no more than unavoidable outages, is important. Good upkeep of equipment is an essential of civic spirit.

APPENDIX D

A BILL

To provide for the lighting of public highways, bridges, thoroughfares, grounds or places, as a means for improving living conditions upon the farms, safeguarding the traveling public, reducing daytime congestion upon the public roads, and affording better facilities for the public convenience and safety; and to authorize the director of highways and the boards of county commissioners to enter into contracts for such services, and to repeal section 7561 of the General Code.

Be it enacted by the General Assembly of the State of Ohio:

2 SECTION 1. The director of highways may, subject to the limita-
3 tions hereinafter provided, at any time when in his opinion it is necessary
4 or advisable for the best interests of the state or for the convenience and
5 safety of the public, by resolution entered on his journal, provide for the
6 lighting of any section of a state road for any period of time not to exceed
7 ten years, and also for the manner and extent of such lighting, the
8 mode of use of such highways, by lines, appliances and devices for such
9 lighting, including the location of poles, and all other matters proper,
10 necessary or advisable in connection with such lighting, and may enter
11 into contracts with any corporation, firm or individual, a public utility,
12 for the lighting of such state roads, including any part thereof within
13 the limits of any village; but none of the provisions of section 2288-2
14 of the General Code shall apply to any such contracts; provided, however,
15 that such contracts for the installation and operation of lights shall be
16 limited to such state highways as have a daily average of not less than
17 600 vehicles per twenty-four hour day for a period of three months as
18 shall be determined by a traffic survey made by the director of highways,
19 and provided further, that the director of highways shall also be author-
20 ized to contract for the installation of lights at railroad crossings, bridges,
21 curves and intersections, located upon the state highway system where
22 in his opinion such lights are necessary for the safety of the traveling
23 public. The cost of such lighting shall be paid by the treasurer of the
24 state upon warrant of the auditor of state. The warrant of the auditor
25 shall be issued upon the requisition of the director of highways and be
26 paid from any appropriation or funds available for such lighting, or
27 for the maintenance or repair of such highways. Such director of high-
28 ways and the board of county commissioners of any county, or the council
29 of any village, are authorized to enter into a contract providing for the
30 payment by such county or village of such portion of the expense incurred
31 under this section as may be agreed upon therein.

32 The proportion of the expense to be paid by the county or village
33 shall be paid by the treasurer of the county or treasurer of the village

34 in which the highway is located, upon the warrant of the county auditor
35 or clerk of the village, issued upon the requisition of the director of high-
36 ways. Such warrant shall be paid from any funds in the county treasury
37 or village treasury available for such lighting or for the maintenance or
38 repair of such roads or highways, and shall be paid into the state treasury
39 to the credit of the lighting fund or other funds separately provided for
40 the maintenance and repair of state roads. None of the provisions for
41 section 5660 of the General Code shall apply to any such contract between
42 such director of highways and such boards of county commissioners or
43 council of any village. This section shall not be deemed to authorize
44 such director of highways to purchase, acquire, or construct such system
45 of lighting, poles, wires or equipment or to acquire, construct or operate
46 a light or power plant.

47 SECTION 2. The board of county commissioners of any county may
48 at any time, when in their opinion it is necessary or advisable for the best
49 interests of the county or for the convenience and safety of the public,
50 by resolution provided for the lighting of the public highways, bridges,
51 thoroughfares, grounds or places, or any of the same or any parts thereof
52 under their jurisdiction, by electricity, for any period of time not ex-
53 ceeding ten years, and also for the manner and extent of such lighting,
54 the mode of use of such highways, by lines, appliances and devices for
55 such lighting, including the location of poles, and all other matters proper,
56 necessary or advisable in connection with such lighting, and may enter
57 into contracts with any corporation, firm or individual, a public utility
58 for the lighting of such public highways, bridges, thoroughfares, grounds
59 or places, provided, however, that such contracts for the installation and
60 operation of lights shall be limited to such county roads as have a daily
61 average traffic of not less than 600 vehicles per twenty-four hour day for
62 a period of three months as determined by a traffic survey made by either
63 the director of highways or the board of county commissioners.

64 The board of county commissioners of any county and the council
65 of any village are authorized to enter into a contract providing for the
66 payment by such village of such portion of the expense incurred under
67 this section as may be agreed upon therein; and payments made by such
68 village under the authority of this section shall be paid into the county
69 fund provided for the lighting of such roads. None of the provisions
70 of section 5660 of the General Code shall apply to any contract authorized
71 herein. Payment of the cost of such lighting shall be made from any
72 revenue or fund available for such purpose, including funds for the main-
73 tenance and repair of highways, and should such revenue or fund be
74 insufficient, then the board of county commissioners shall provide for the
75 payment of the balance of the cost of such lighting from the general
76 county funds. Such payments shall be made by the county treasurer
77 upon warrant of the county auditor issued upon requisition of the board
78 of county commissioners.

79 Authority to provide for such lighting shall not be deemed to author-
80 ize the board of county commissioners to purchase, acquire, construct
81 or own such system of lighting, poles, wires or equipment, or to pur-
82 chase, acquire, construct or operate a light or power plant. Provided

83 further, that such authority shall not apply to or extend to bridges within
84 the limits of a city which have been constructed by the board of county
85 commissioners. In such cases the city shall light the bridges within the
86 corporate limits.

87 SECTION 3. When it is deemed advisable or necessary for the public
88 convenience and safety, the boards of county commissioners of two or
89 more counties may jointly by resolution provide for the lighting of public
90 highways and thoroughfares extending into or through the several coun-
91 ties, or of any joint county roads, bridges, or grounds or places jointly
92 owned or used by the several counties of the public generally, by elec-
93 tricity, for any period of time not to exceed ten years, and also for the
94 manner and extent of such lighting, the mode of use of such highway
95 by lines, appliances and devices for such lighting, including the location
96 of poles or other matters proper, necessary or advisable in connection
97 with such lighting and may enter into contract with any corporation,
98 firm or individual, a public utility, for the lighting of such highways,
99 bridges, thoroughfares, grounds or places.

100 Such board of county commissioners shall provide for the payment
101 thereof by the counties interested in the same proportion as the expense
102 of the building of such public highways or joint county roads, bridges,
103 public places or public grounds was paid or in such proportion as the
104 board of county commissioners may agree, from any revenue or fund for
105 the maintenance and repair of highways, and should such revenue or
106 funds be insufficient, then the board of county commissioners shall pro-
107 vide for the payment of the balance of the cost of such lighting from
108 the general county funds. All such payments shall be made by the county
109 treasurer upon warrant of the county auditor, issued upon order of the
110 board of county commissioners; provided, however, that the boards
111 of county commissioners of counties acting as a joint board shall be
112 limited in such contracts for the installation and operation of such lights
113 to such joint county roads as have a daily average traffic of not less than
114 600 vehicles per twenty-four hour day for a period of three months as
115 determined by a traffic survey made by the director of highways or the
116 joint boards of county commissioners.

117 The boards of county commissioners of the several counties, or the
118 board of county commissioners of any county and the council of any
119 village are authorized to enter into a contract providing for the payment
120 by such village of such portion of the expense incurred under this sec-
121 tion as may be agreed upon therein; and payments made by such village
122 to the county under the authority of this section shall be made by the
123 treasurer of the village upon warrant of the village clerk issued upon
124 requisition of the board of county commissioners, and paid into the funds
125 of such county provided for the lighting of such road. Such payments
126 by the village shall be made from any revenue or funds available for
127 such purpose, including funds for the maintenance and repair of high-
128 ways, and should such revenue or funds be insufficient, then the council
129 of such village shall provide for the payment of the balance of the cost
130 of such lighting from the general funds of said village.

131 None of the provisions of section 5660 of the General Code shall
132 apply to any contracts authorized herein. Such authority to provide for

133 such lighting shall not be deemed to authorize the board of county com-
134 missioners to purchase, acquire, construct or own such system of lighting,
135 poles, wires or equipment or to purchase, acquire, construct or operate
136 a light or power plant.

137 SECTION 4. Where such lighting contract relates to a state highway
138 or a part thereof, no pole lines, wires or other equipment shall be erected
139 in such road or highway until plans for the location and erection of
140 such poles, wires, and other equipment shall have been submitted to and
141 approved by the director of highways, and where such contract relates
142 to any public highway or public place other than a state highway, no
143 pole lines, wires or other equipment shall be erected in such road or
144 highway until plans for the location of such poles, wires and other
145 equipment shall have been submitted to and approved by the county sur-
146 veyor of the county in which such roads or highways are situated.

147 The board of county commissioners of any county is authorized and
148 empowered to grant permission and authority to any corporation, firm
149 or individual, a public utility, for the construction, erection, maintenance,
150 operation and repair of pole lines, wires, equipment and apparatus for
151 the transmission and distribution of electricity on, along and across the
152 public roads, highways, thoroughfares, grounds or places within such
153 county under their jurisdiction.

154 SECTION 5. The word "highway" as used in this act includes
155 and shall be held to mean any national, state, county or township roads
156 which have been or may hereafter be located, established or con-
157 structed. The word "places" as used herein shall include and be held
158 to mean all state and county buildings outside municipal corporations,
159 including infirmaries, children's homes, hospitals, schools, fair grounds
160 or any other institution, and all premises or lands used by the public for
161 assembly, park, educational or recreational purposes.

162 Funds provided by law for maintenance and repair of roads or
163 highways by the state or by counties or villages shall be available for
164 the payment of all costs and expenses incurred under contracts author-
165 ized by this act.

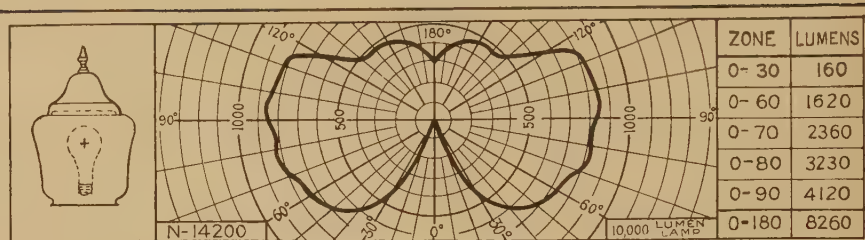
166 With the exception of section 2288-2 and 5660 of the General Code,
167 all statutory provisions applicable to the preparation of plans and specifi-
168 cations for highway improvements and to advertising and receiving bids
169 therefor, and to entering into contracts for such improvements, relating
170 to the director of highways or to boards of county commissioners, shall
171 apply to such officials in their proceedings under this act; provided,
172 however, that any statutory provisions relating to the taking of a bond
173 from a successful bidder and covering performance of contract shall
174 not apply.

175 SECTION 6. Each section and each subdivision of any section of
176 this act is hereby declared to be independent, and the finding and holding
177 of any section or subdivision of any section thereof to be unconstitutional,
178 invalid or void, shall not be deemed or held to affect the validity of any
179 other section or subdivision.

180 SECTION 7. That section 7651 of the General Code and all other
181 sections or parts of sections inconsistent herewith be, and the same are,
182 hereby repealed.

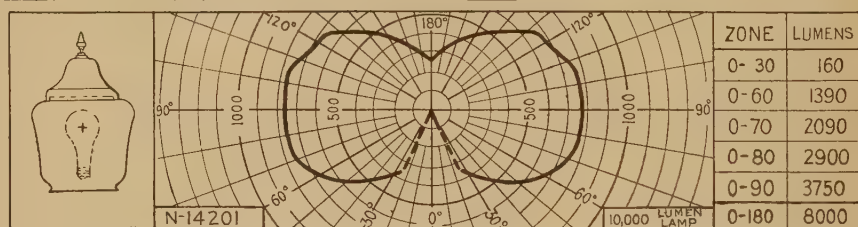
183 SECTION 8. This act may be referred to as the highway lighting act.

APPENDIX E
REPRESENTATIVE CANDLEPOWER DISTRIBUTION
CURVES



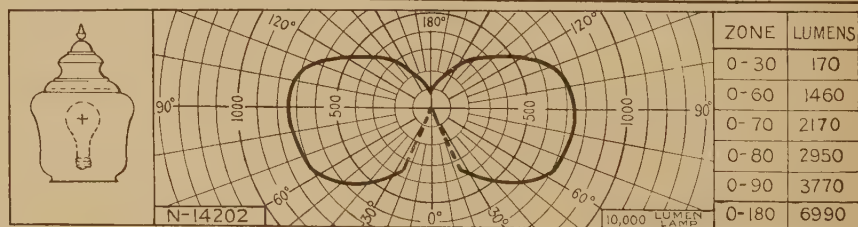
CURVE 1.—Upright globe and canopy of light alabaster rippled glass.

This light distribution is representative of upright ornamental units in which both globe and canopy are of rippled, stippled, or pebbled glass containing a small amount of "opal"—that is, white particles in suspension.



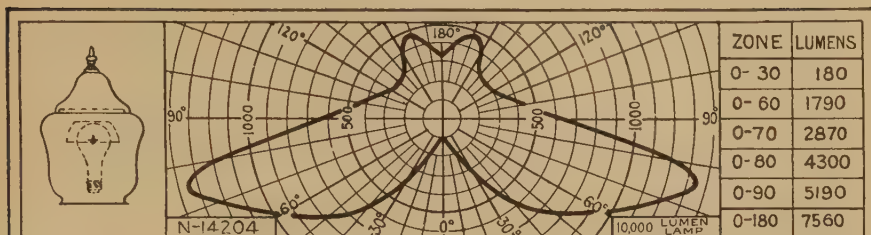
CURVE 2.—Upright globe and canopy of medium alabaster rippled glass.

As compared with Curve 1, Curve 2 shows that the greater diffusion of a globe of medium alabaster glass, resulting from its higher opal content, is accompanied by a slight reduction in the light output.



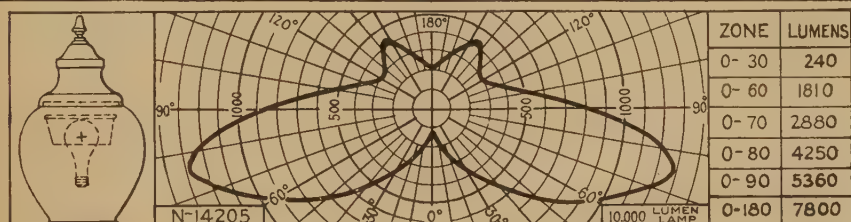
CURVE 3.—Upright globe of medium alabaster rippled glass, with metal canopy.

Comparison with Curve 2 shows that a canopy of metal instead of glass has very little effect upon the downward light, but at night the metal-top unit presents a less finished appearance.



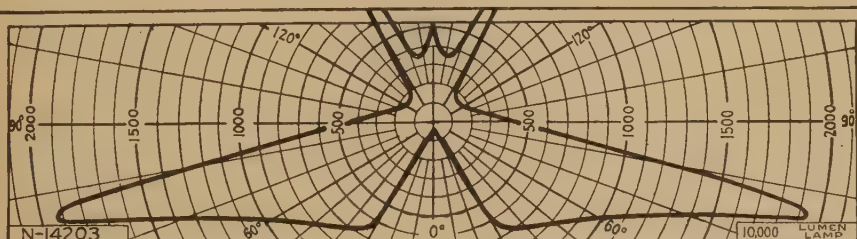
CURVE 4.—Upright globe and canopy of light alabaster rippled glass, with symmetrical dome refractor No. 4632 set for 75° max.

In comparison with Curve 1, a dome refractor in this unit increases the downward light about 10 points, the majority of this increase occurring at the most favorable angles.



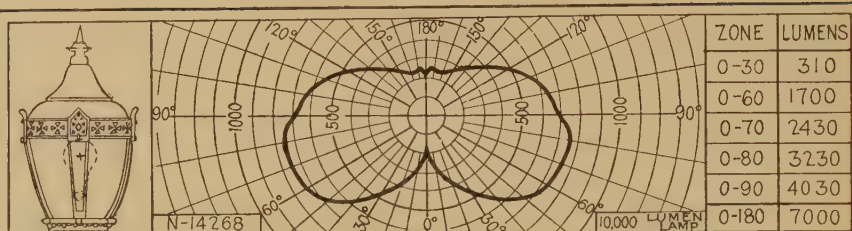
CURVE 5.—Large upright globe and canopy of medium alabaster rippled glass, with inner section only of large band refractor No. 4429 set for 75° max.

This combination makes it possible to obtain the refractor distribution in large upright ornamental units employing PS-52 bulb lamps.



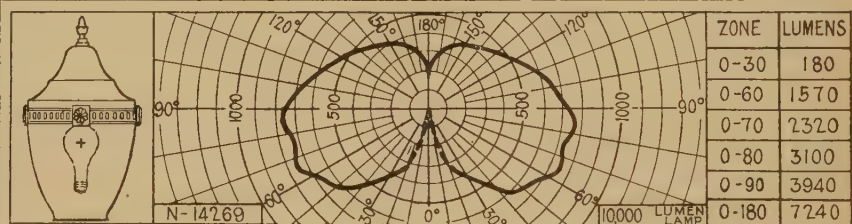
CURVE 6.—Upright globe and canopy of clear rippled glass, with symmetrical dome refractor No. 4632 set for 75° max.

Compared with curves 4 and 5, clear rippled glass increases the downward directional light, but not the total output.



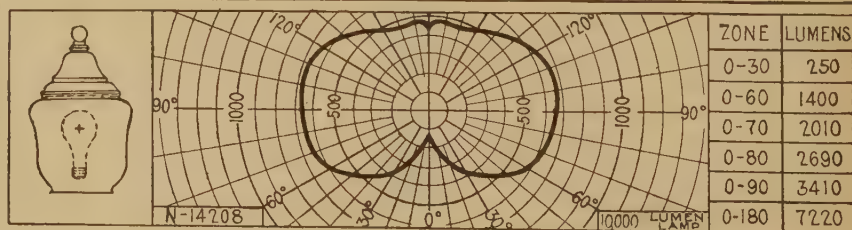
CURVE 7.—Upright globe of light alabaster and canopy of heavy alabaster rectilinear glass, with ornamental perforated metal band and vertical ribs.

In this type of unit, if the vertical ribs are omitted the output is increased about 4 points.



CURVE 8.—Upright globe and canopy of medium alabaster rippled glass, with ornamental perforated metal band.

The metal band cuts down the total output about 7 points, in comparison with Curve 2, but the loss is all in the upper hemisphere.



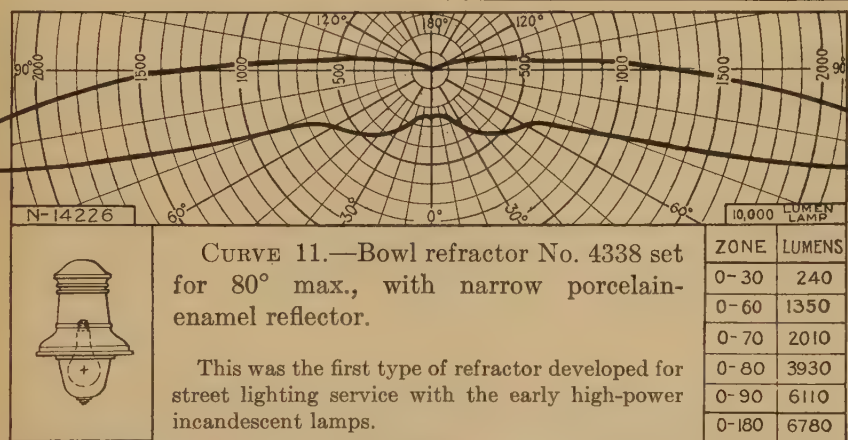
CURVE 9.—Upright globe and canopy of white diffusing glass. Slightly more than half the light emitted by this unit is above the horizontal.

White diffusing glass is being largely superseded for street lighting.



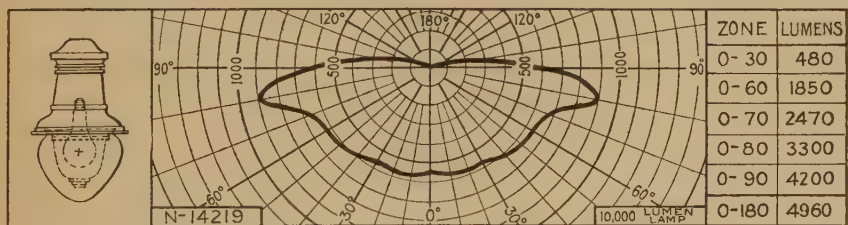
CURVE 10.—Pendent globe of white diffusing glass, with narrow porcelain-enamel reflector.

This was the first type of equipment in which the early high-power incandescent lamps were used for street lighting. It is not surprising that attempts were made to combine this globe with the refractor in Curve 11.



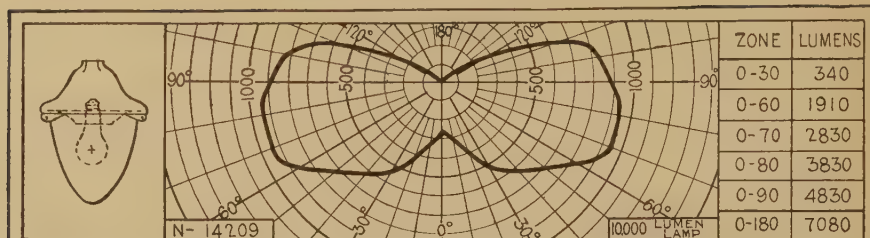
CURVE 11.—Bowl refractor No. 4338 set for 80° max., with narrow porcelain-enamel reflector.

This was the first type of refractor developed for street lighting service with the early high-power incandescent lamps.



CURVE 12.—Pendent globe of white diffusing glass, with narrow porcelain-enamel reflector and bowl refractor No. 4338 set for 80° max.

This shows the fallacy of combining a white glass globe and refractor. The white glass negatives largely the refractor distribution, and the absorption is increased.



CURVE 13.—Pendent globe of clear rippled glass, with white porcelain-enamel internal reflector.

Besides having a higher output than the white glass in Curve 10, clear rippled glass does not materially alter the vertical distribution of the light source and it is therefore suitable as an envelope for refractors.



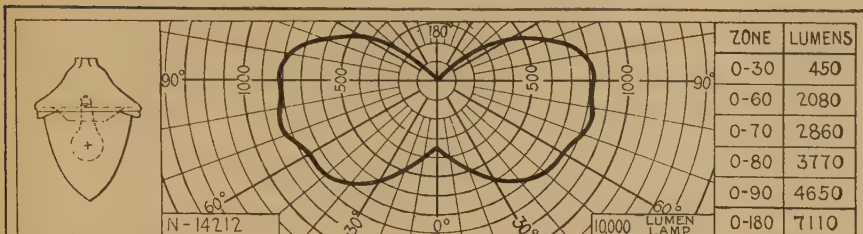
CURVE 14.—Pendent globe of clear rippled glass, with white porcelain-enamel internal reflector and dome refractor No. 4632 set for 75° max.

The refractor increases the downward light about one-third, particularly in the most favorable angles.



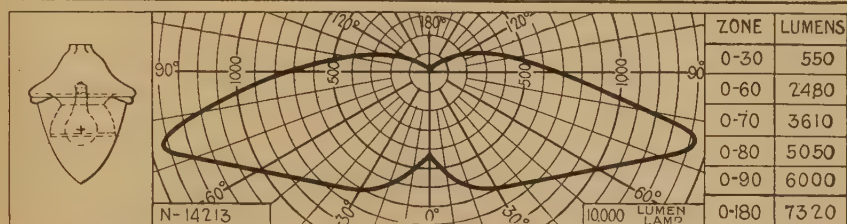
CURVE 15.—Pendent globe of clear rippled glass, with white porcelain-enamel internal reflector, dome refractor No. 4632 set for 75° max., and ornamental basket.

This basket, comprising one horizontal and five vertical bands, provides an ornamental appearance and avoids hazard from falling glass in case of globe cracking.



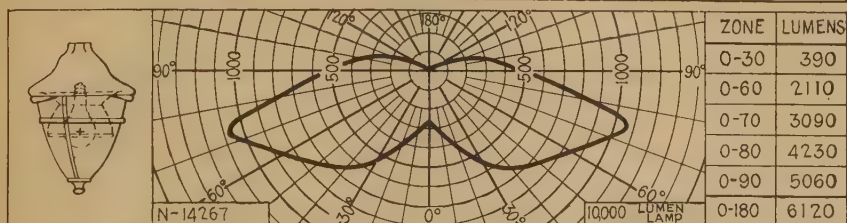
CURVE 16.—Pendent globe of light alabaster rippled glass, with white porcelain-enamel internal reflector.

Where somewhat greater diffusion is desired, as in the case of units designed for the larger lamps, light alabaster rippled glass may be employed instead of clear rippled glass.



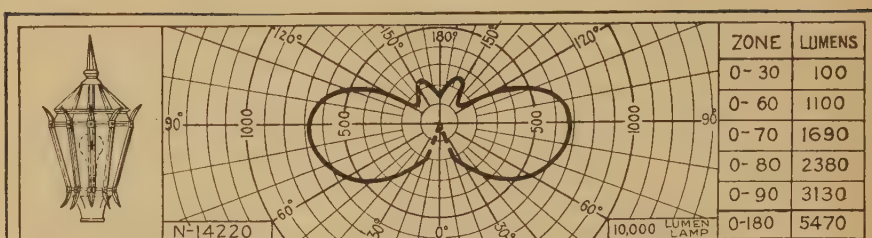
CURVE 17.—Pendent globe of light alabaster rippled glass, with white porcelain-enamel internal reflector and dome refractor No. 4632 set for 75° max.

The curves on these two pages show that in each case the light opal flashing lowers slightly the peak candle-power and the downward light, but does not, in this type of unit, affect the total output.



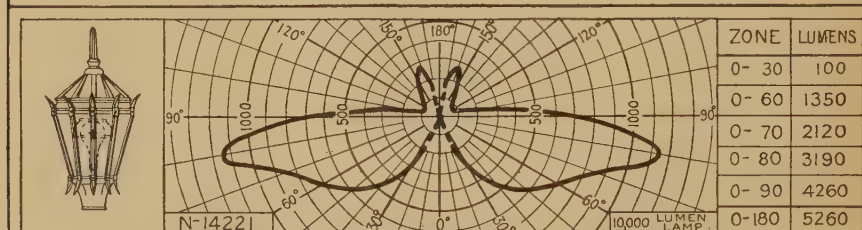
CURVE 18.—Pendent globe of light alabaster rippled glass, with white porcelain-enamel internal reflector, dome refractor No. 4632 set for 75° max., and ornamental basket.

Omitting the horizontal band on this basket lessens the ornamental appearance but increases the output about 8 points, mostly in the lower hemisphere.



CURVE 19.—Small upright octagonal lantern, with side and top panels of clear stippled glass.

As would be expected, the ribs of lantern-type units intercept some of the light and the total output is therefore less than that of globe-type units such as those in Curves 1, 2, 7, and 8.



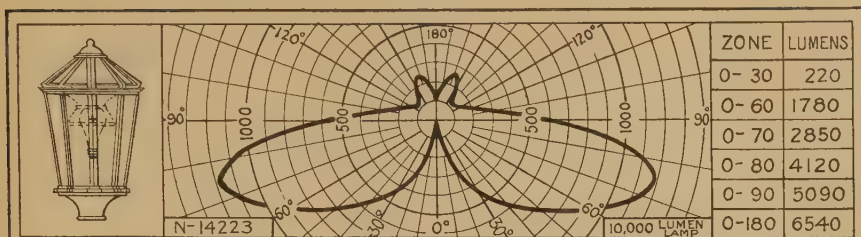
CURVE 20.—Large upright octagonal lantern, with side and top panels of clear stippled glass and dome refractor No. 4632 set for 80° max.

Comparison with Curve 19 shows that in a lantern a refractor increases materially the downward light, with little change in the total output.



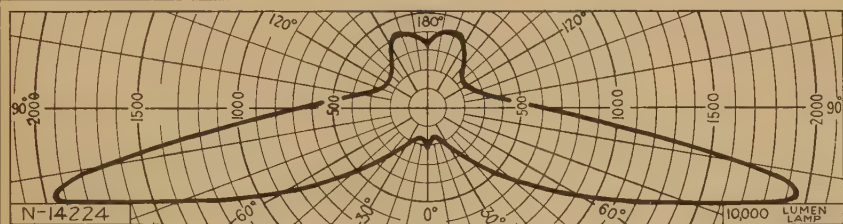
CURVE 21.—Large upright octagonal lantern, with side and top panels of light alabaster cathedral glass, aluminum finish reflector, and dome refractor No. 4632 set for 80° max.

This lantern has a higher output than the one in Curve 20 because there is relatively less metal to obstruct the light.



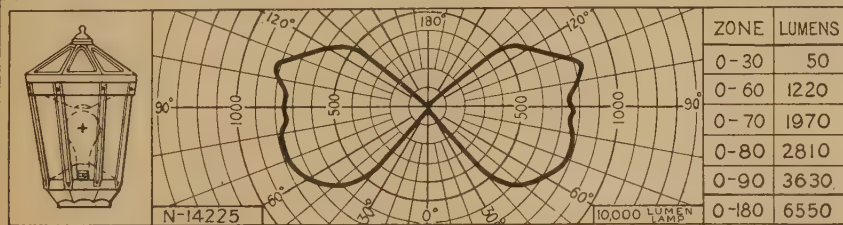
CURVE 22.—Large upright octagonal lantern, with side panels of light alabaster colonial glass, top panels of clear colonial glass, aluminum finish reflector, and dome refractor No. 4632 set for 75° max.

The difference in output between this unit and the one in Curve 21 is due to the difference in the glass panels.



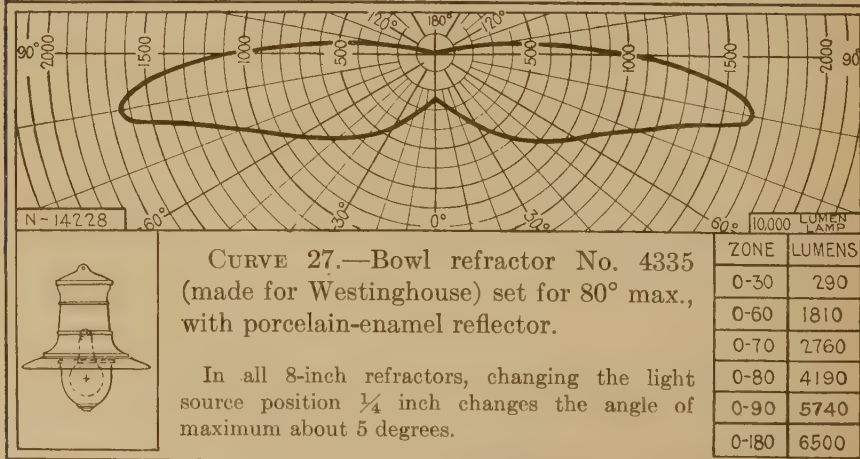
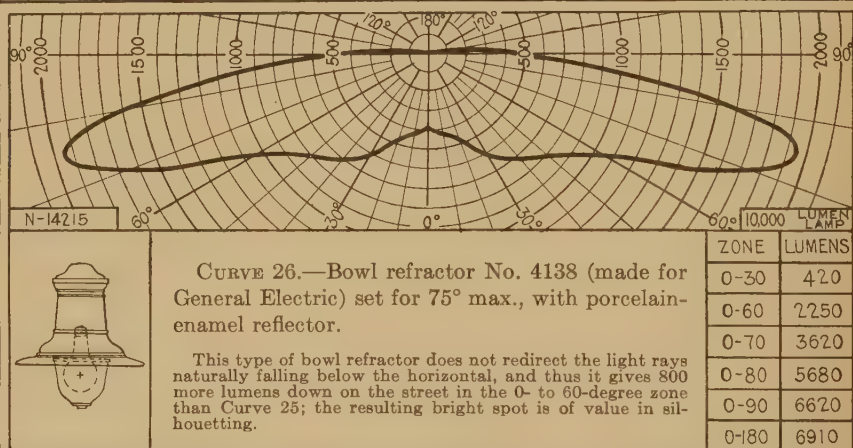
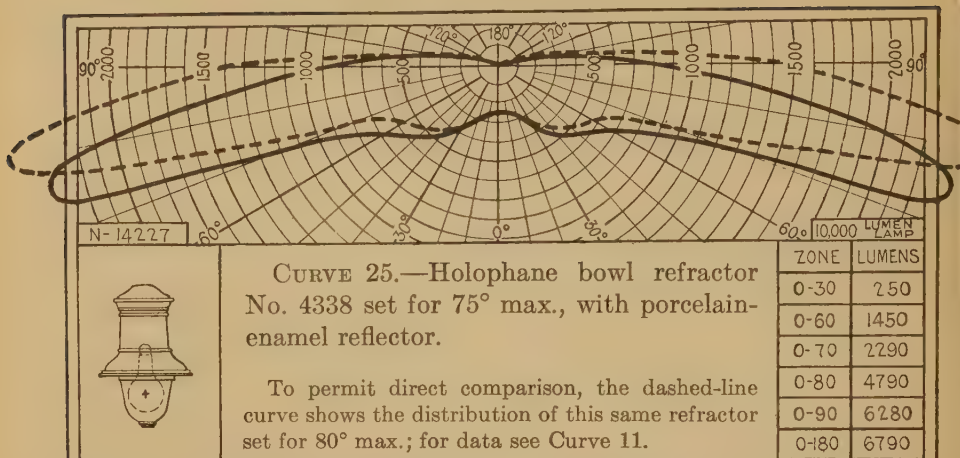
CURVE 23.—Upright ornamental symmetric refractor No. 4937 and canopy No. 4937 satin finish, set for 75° max.

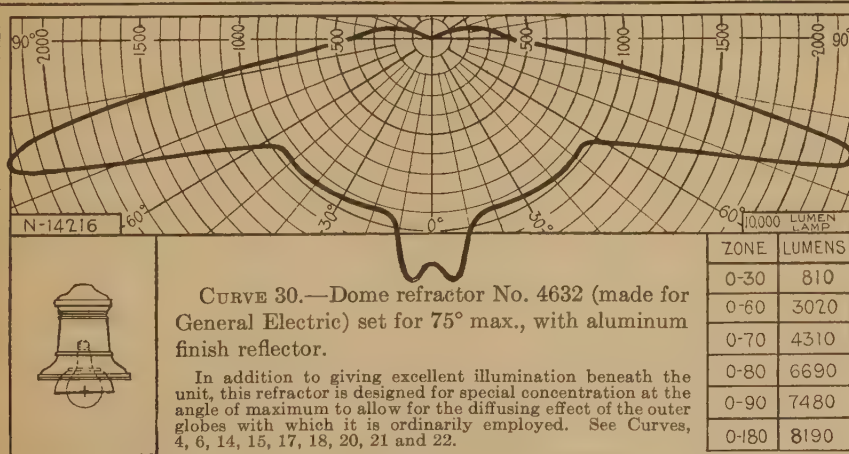
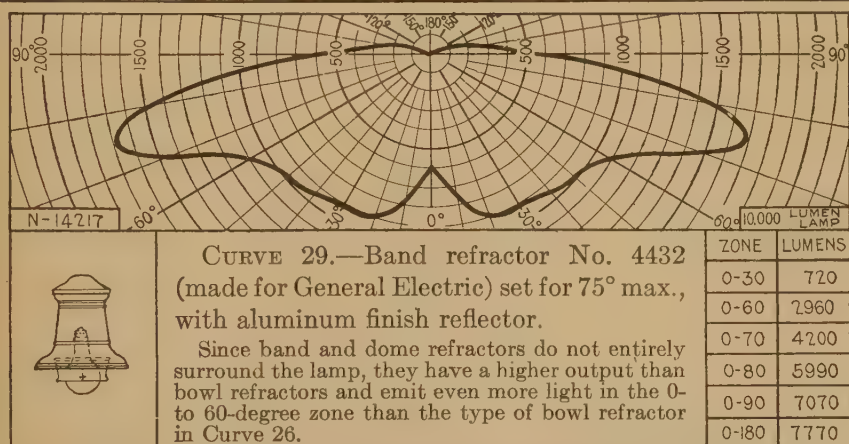
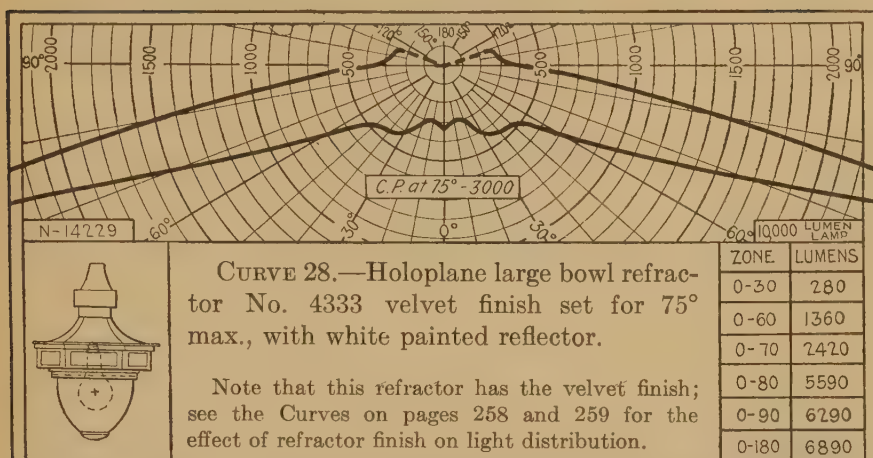
This refractor unit is designed with ornamental contour to permit its use without an enclosing envelope, such as rippled glass.

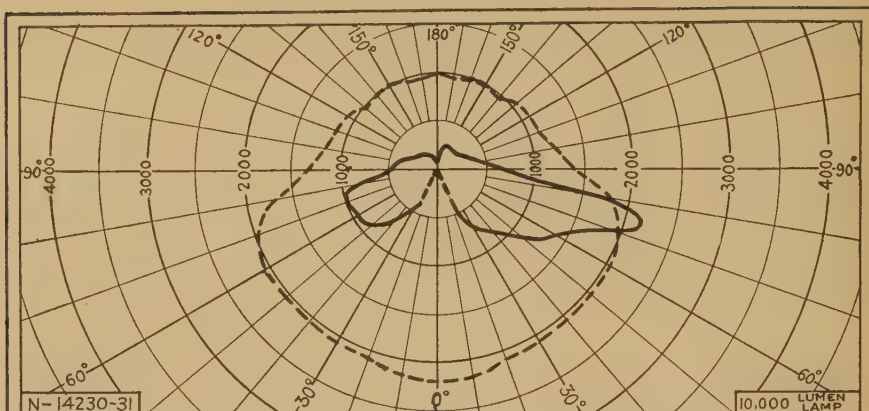


CURVE 24.—Small upright octagonal lantern, with side panels of vertically ribbed clear glass, metal canopy, and porcelain-enamel reflectors top and bottom.

The reflectors above and below the light source intercept most of the light in the 0- to 30-degree and the 130- to 180-degree zones, and redirect it laterally.





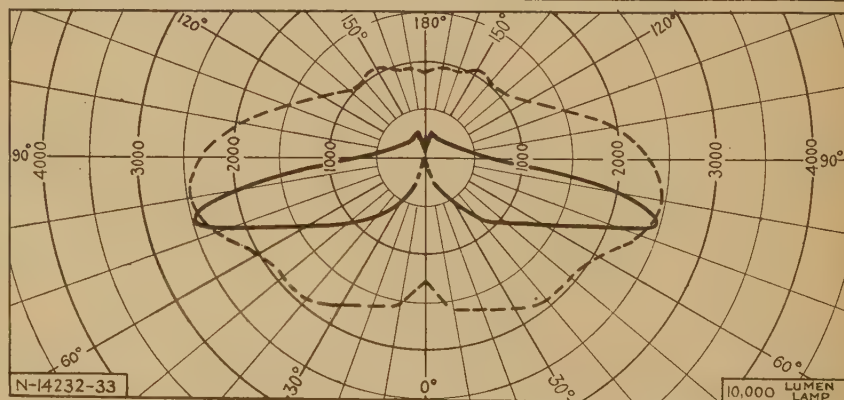


CURVE 31.—Upright globe and canopy of light alabaster rippled glass, with A-sym-etric dome refractor No. 4633 (made for General Electric) set for 75° max.

Solid line curve—Distribution in vertical plane showing sidewalk and street sides.

Dotted line curve—Distribution in 75° lateral cone.

In many locations a non-symmetrical refractor distribution of light is more economical than a symmetrical distribution, such as in Curve 4. The two curves on this page also represent the results obtained with these refractors in pendent globes, except that about 700 lumens will be transferred from the upper hemisphere to the 0- to 60-degree zone.



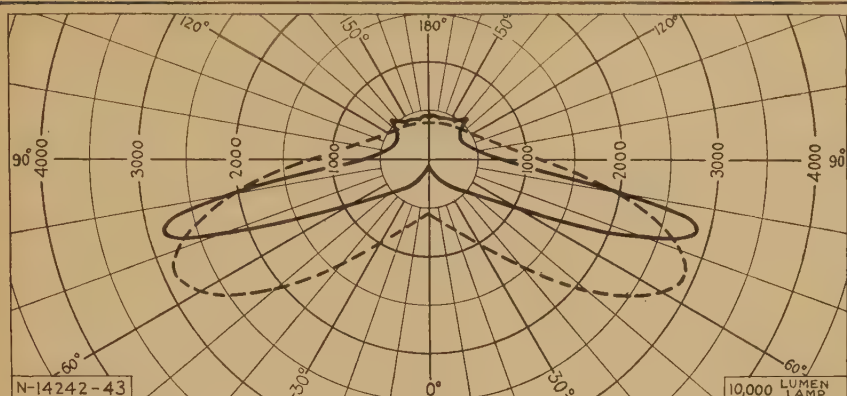
CURVE 32.—Upright globe and canopy of light alabaster rippled glass, with B-sym-etric dome refractor No. 4634 (made for General Electric) set for 75° max.

Solid line curve—Distribution in 2 maximum vertical planes 10° from curb.

Dotted line curve—Distribution in 75° lateral cone.

The A-sym-etric distribution in Curve 31 provides about the same amount of light at all angles on the street side of the unit, while the B-sym-etric distribution provides relatively more light up and down the street. Compare with the clear rippled pendent unit in Curve 40.



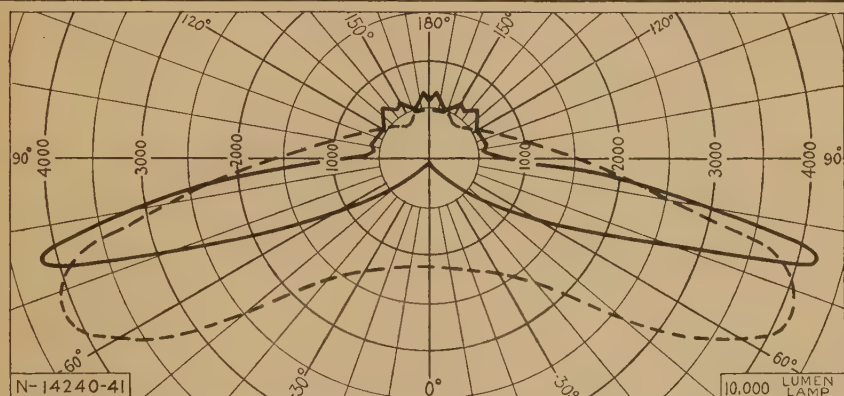


CURVE 33.—Upright globe and canopy of rectilinear light alabaster glass, with Bi-lux refractor No. 4374 (made for Westinghouse) set for 75° max.

Solid line curve—Distribution in 2 maximum vertical planes 22½° from curb.

Dotted line curve—Distribution in 75° lateral cone.

Compared with Curve 32, the refractors in the two units on this page go even further in concentrating the light up and down the street.



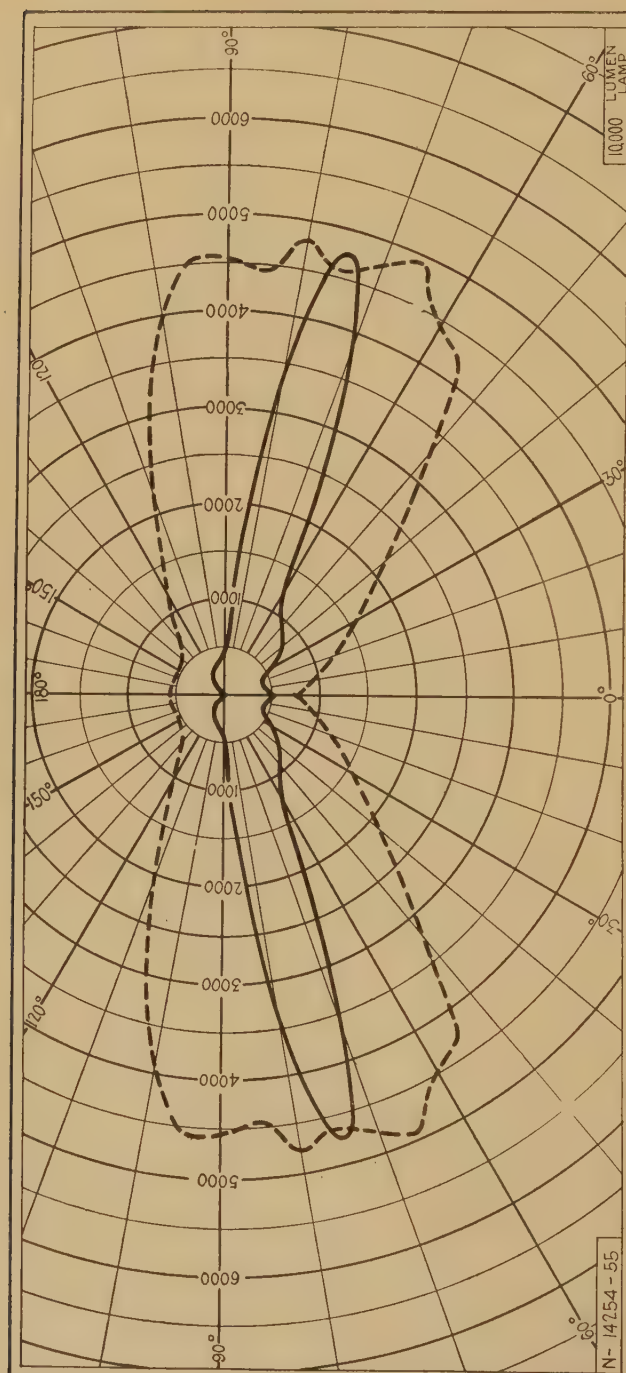
CURVE 34.—Upright globe and canopy of rectilinear light alabaster glass, with Bi-lux refractor No. 4372 (made for Westinghouse) set for 75° max.

Solid line curve—Distribution in 2 maximum vertical planes 22½° from curb.

Dotted line curve—Distribution in 75° lateral cone.

It will be noted that, except in Curve 31, the two wings of the vertical distribution curves of asymmetric units are in two different planes.



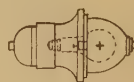


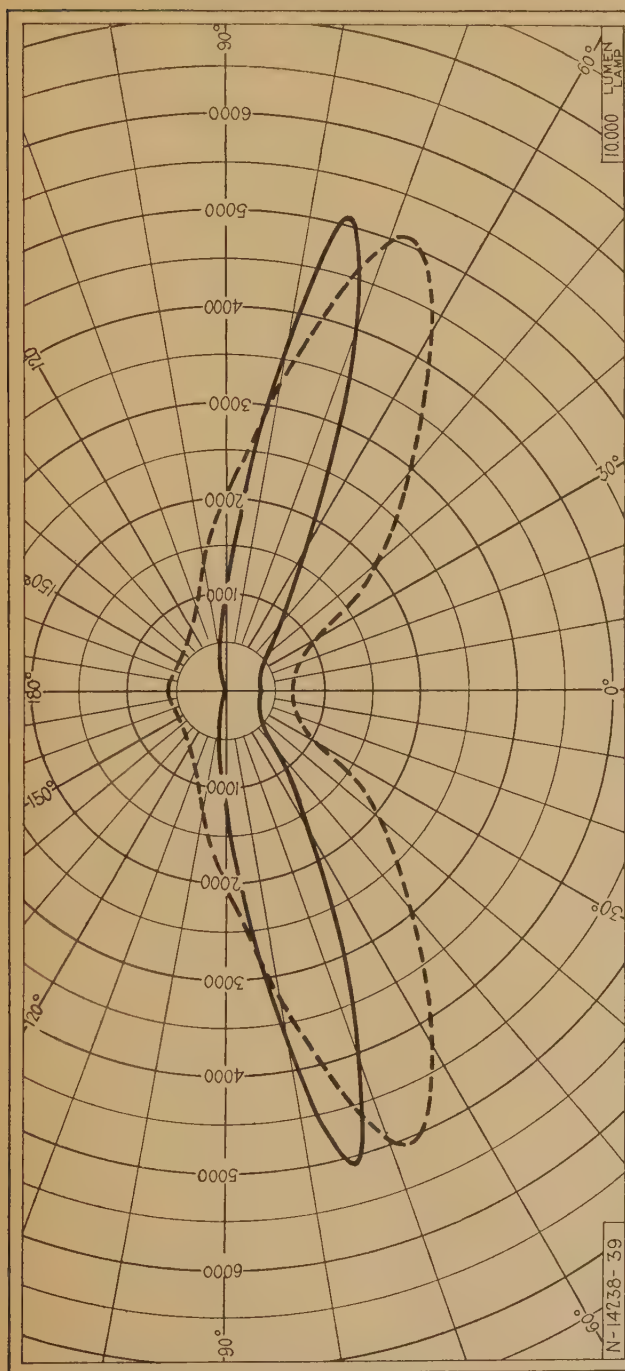
CURVE 35.—Holophane asymmetric B-way refractor No. 4377 set for 75° max.

Solid line curve—Distribution in 2 maximum vertical planes 10° from curb.

Dotted line curve—Distribution in 75° lateral cone.

With this asymmetric design of refractor about twice the candle-power up and down the street is obtained as compared with the symmetrical refractor in Curve 30. Much higher mountings, of the order of 30 feet, are required with this distribution to avoid objectionable glare.



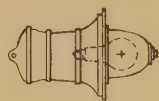


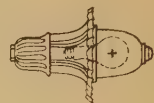
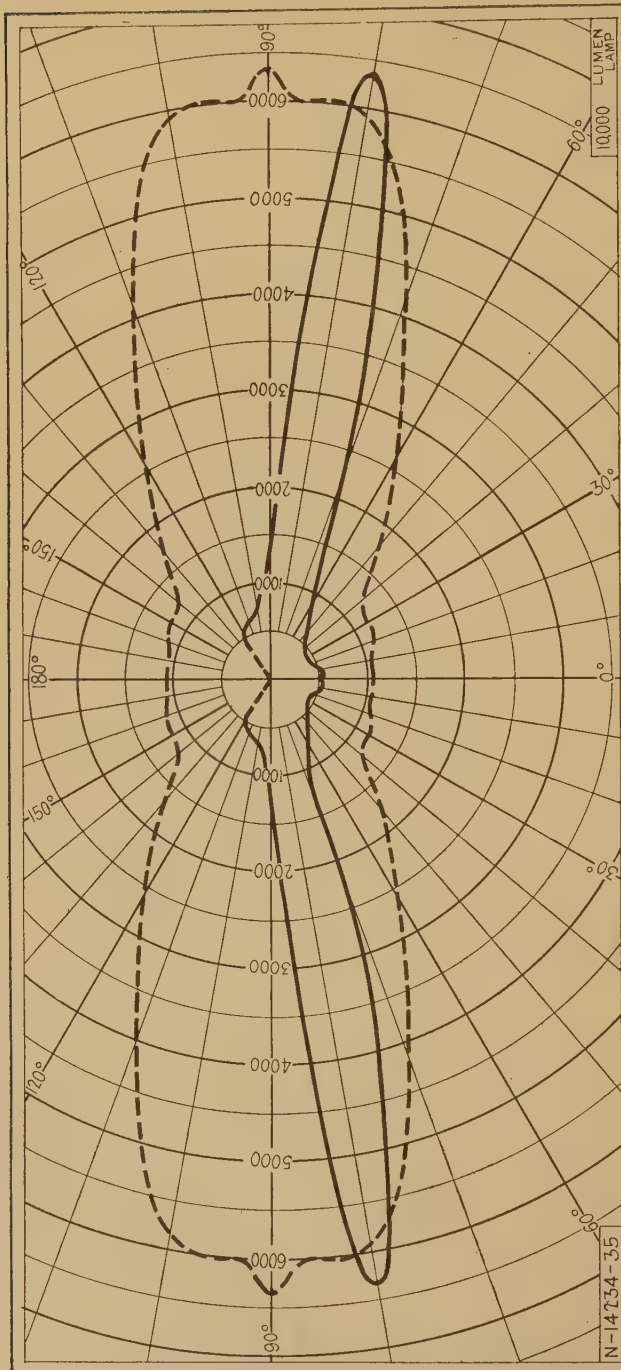
CURVE 36.—Asymmetric Bi-lux bowl refractor No. 4274 velvet finish (made for Westinghouse) set for 75° max.

Solid line curve—Distribution in 2 maximum vertical planes 22½° from curb.

Dotted line curve—Distribution in 75° lateral cone.

This refractor, designed for pendent units, gives a similar distribution to the corresponding refractor for upright units in Curve 33. Compared with Curve 35, this refractor has approximately the same concentration but directs the light diagonally across the street.



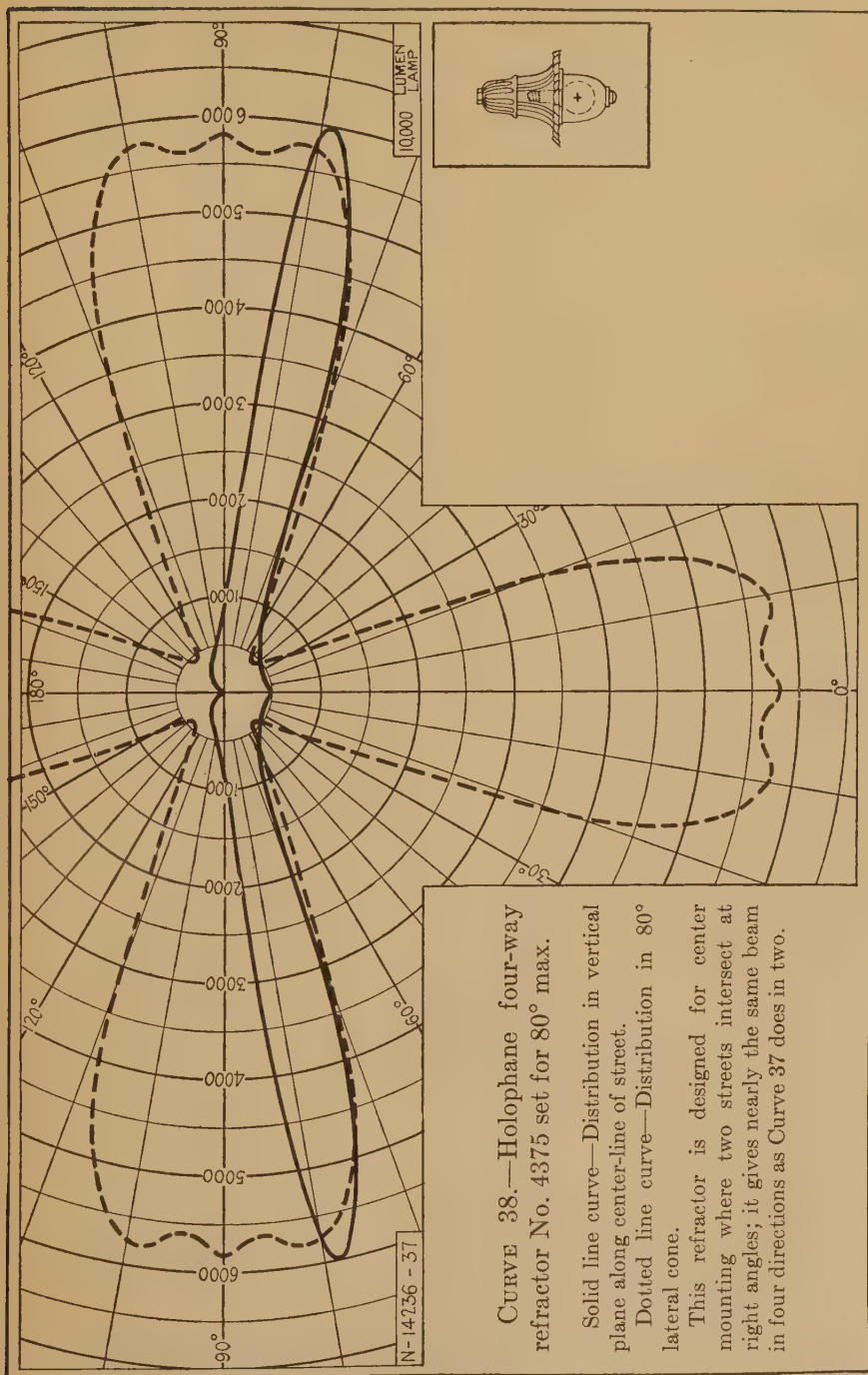


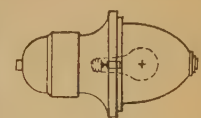
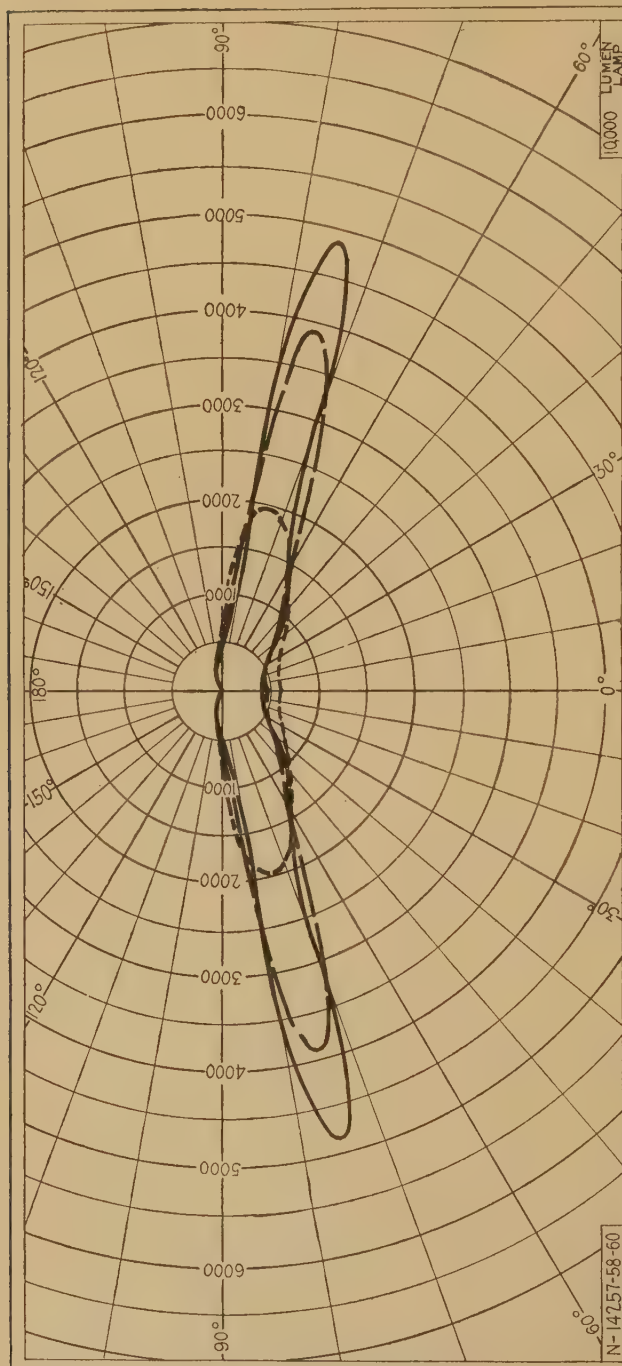
CURVE 37.—Holophane two-way refractor No. 4376 set for 80° max.

Solid line curve—Distribution in vertical plane along center-line of street.

Dotted line curve—Distribution in 80° lateral cone.

This refractor is designed for mounting above the center of a street, from which location it directs most of the light up and down the street; it has an even higher candlepower than the refractors in Curves 35 and 36, and therefore a 30-foot mounting height should be considered the absolute minimum.





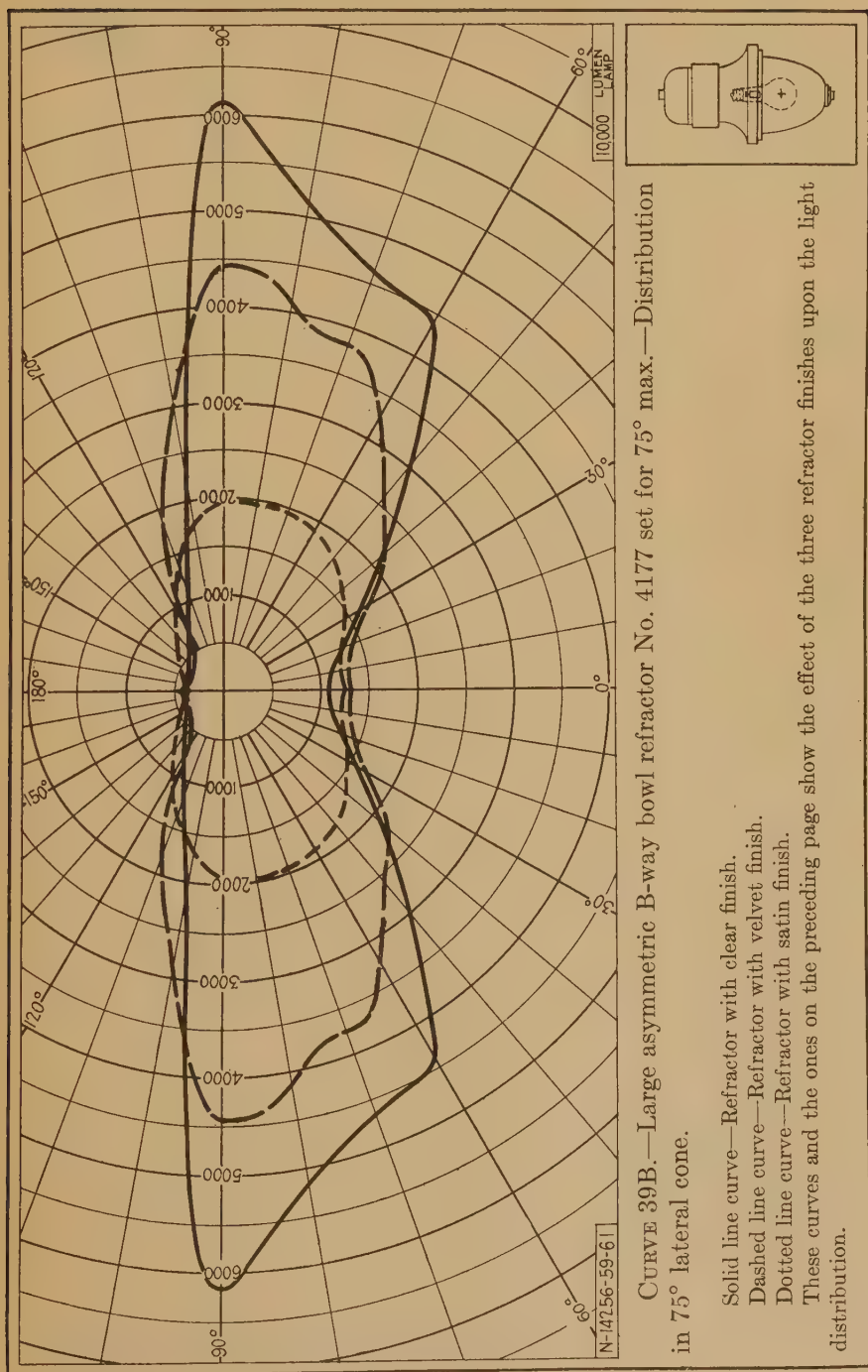
CURVE 39A.—Large asymmetric B-way bowl refractor No. 4177 set for 75° max. Distribution in 2 maximum vertical planes 15° from curb.

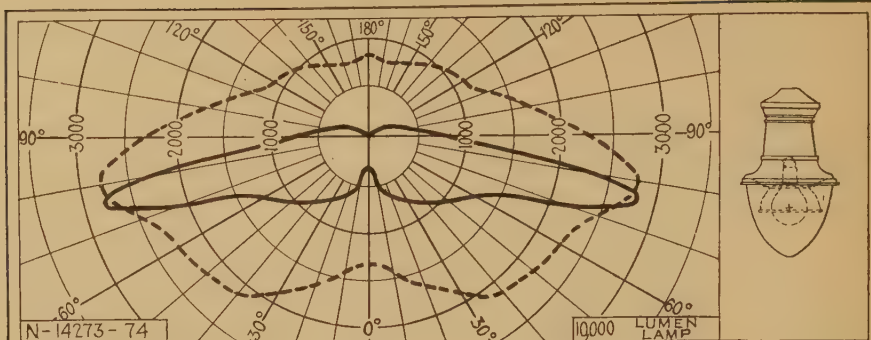
Solid line curve.—Refractor with clear finish.

Dashed line curve.—Refractor with velvet finish.

Dotted line curve.—Refractor with satin finish.

The corresponding distribution curves in the 75° lateral cone are on the next page.



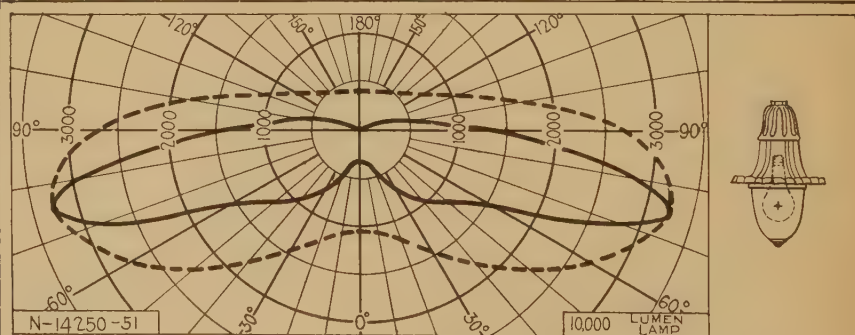


CURVE 40.—Pendent globe of clear rippled glass, with white porcelain-enamel interior reflector and B-sym-etric dome refractor No. 4634 set for 75° max.

Solid line curve—Distribution in 2 maximum vertical planes 10° from curb.

Dotted line curve—Distribution in 75° lateral cone.

This lighting unit is intended for bracket mounting and gives its maximum candlepower lengthwise of the street, as does Curve 35; because of the diffusing effect of the outer globe and the lower beam candlepower, extreme mounting heights are not required. The illumination beneath this unit is excellent.

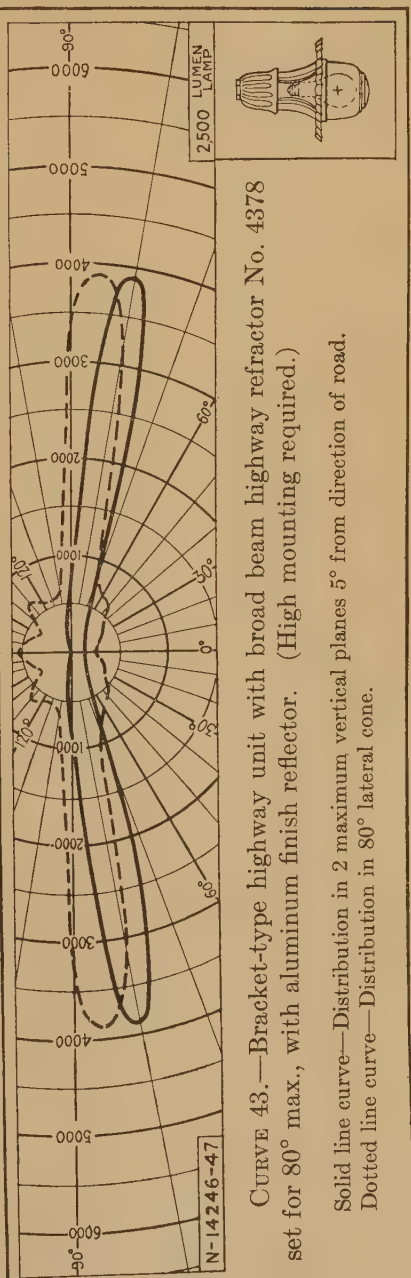
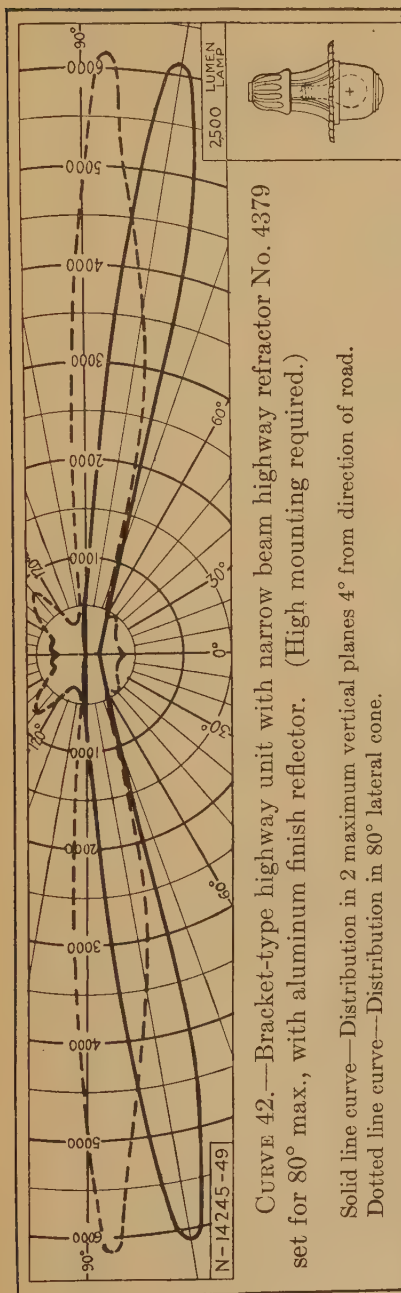


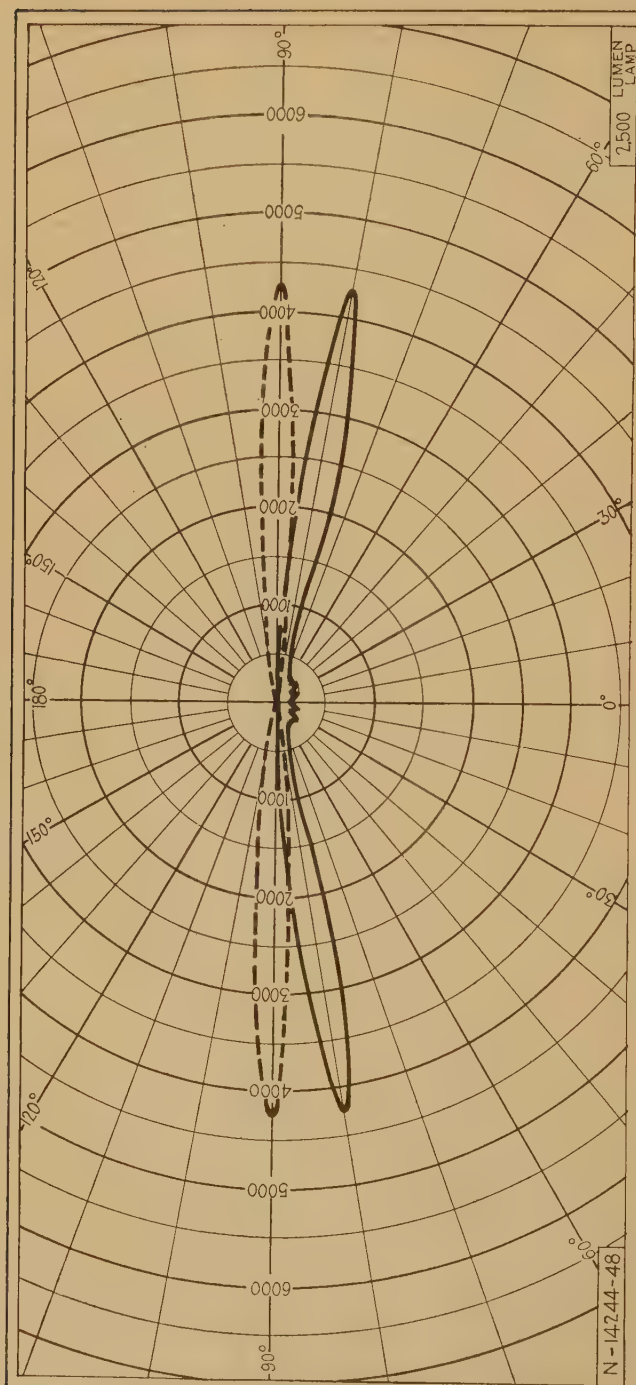
CURVE 41.—B-sym-etric rippled bowl refractor No. 4173 set for 75° max.

Solid line curve—Distribution in 2 maximum vertical planes 15° from curb.

Dotted line curve—Distribution in 75° lateral cone.

This unit is coming to be widely used for highway lighting. Its relatively low brightness permits it to be mounted lower than the more concentrating units, without objectionable glare. The unit in Curve 40 gives about the same distribution and should be used with the larger lamps.



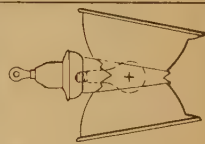


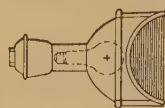
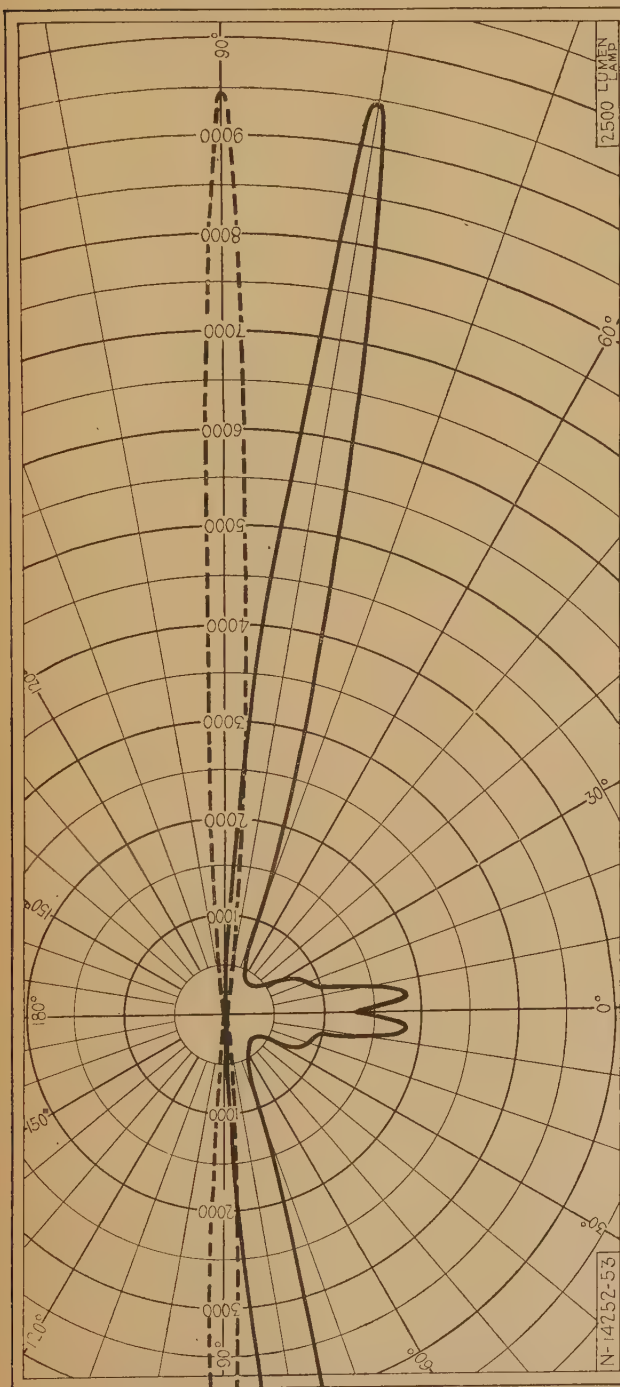
CURVE 44.—Nested parabolic highway unit, with white porcelain-enamel reflecting surfaces.

Solid line curve—Distribution in maximum vertical plane in the direction of the road.

Dotted line curve—Distribution in 80° lateral cone.

This is one of the early units employed for highway lighting. Its over-all efficiency is about 30 points lower than that of the unit in Curve 43, which has a similar distribution; this emphasizes that peak candlepower is *not* a measure of light output.



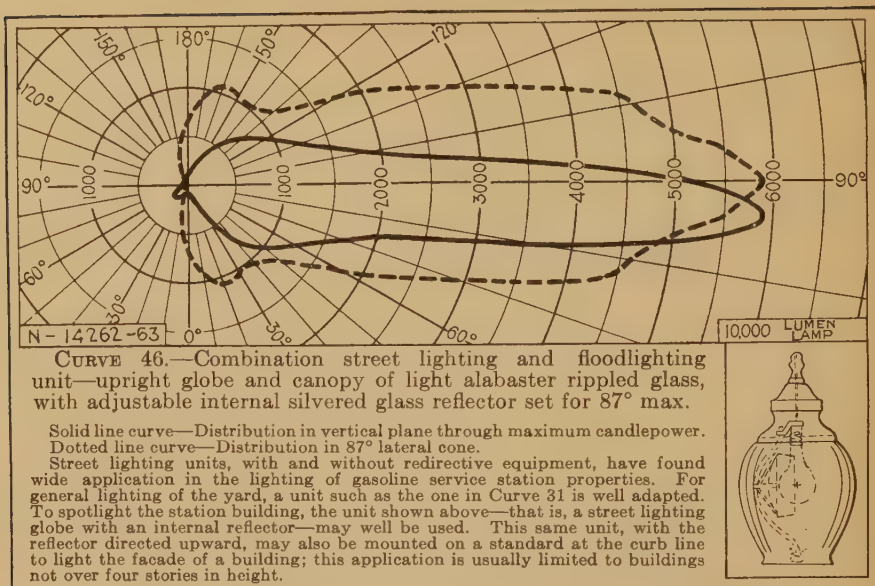


CURVE 45.—Bracket type highway unit with polished metal internal reflector.

Solid line curve—Distribution in maximum vertical plane in the direction of the road.

Dotted line curve—Distribution in 80° lateral cone.

This is another early type of highway lighting unit.



INDEX

A

- Accidents, day and night, 21
 - highway lighting and, 155
 - street lighting and, 14, 145
 - survey, 15, 19
 - traffic, cost of, 14
 - daylight, 21
- Advantages, comprehensive planning, 121
 - highway lighting, 155
 - multiple distribution, 96, 97
 - series distribution, 95
 - street lighting, 14 (see also *Street lighting, benefits*).
 - systematized maintenance, 168
- Alternating current (see *Series lighting systems*).
- Appearance, equipment, 10, 119, 128, 233
 - street, 118, 128, 134, 233
- Appraisal of street lighting, 106, 112, 118
- Arc lamps, 5, 30, 188
 - light distribution, 32, 37
 - magnetite, 37
 - system, Brush, 3, 74
 - Thomson-Houston, 3
- Asymmetric distribution, 158, 213
 - arc lamps, 31
 - isocandle curves, 214
 - refractors, 69, 156, 157
- Autotransformers, 82, 83, 85

B

- Benefits of street lighting (see *Street lighting*).
- Boulevard lighting, 147
- Brackets, 116, 118, 145, 151, 161
 - highway lighting, 159
 - trolley pole, 134, 136

- Brightness, of lighting equipment, 70
 - pavement, 106, 111, 119
- Brush arc system, 3, 74
- Burning hours, 169, 176
- Business-district lighting, 18, 124, 128
 - equipment, 129
 - recommendations, 124, 131

C

- Cable, electrical, 164
 - laying, 99
 - underground, 99, 164
- Calculation, horizontal illumination, 217
 - effective flux method, 221
 - point-by-point method, 217
 - lumens, from candlepower, 220, 211
 - street-lighting costs, 178
- Candlepower, distribution curves, 204, 208, 240
 - explanation of, 196, 202
 - lumens, 200, 211
 - measurement of (see *Measurement of candlepower*).
 - rating of lamps, 199
 - relation of lumens, 200, 211
- Carrier-current control, 92, 104
- Cascade control, 91, 101
- Characteristics of lamps, 47, 50
- Circuits, arc-lamp, series lamps on, 53, 77
 - multiple, series lamps on, 54, 99
 - rectifier, series lamps on, 77
- Cleaning of lighting equipment, 169, 171, 177 (see also *Maintenance*).
- Constant-current transformers, 77, 78, 88, 180
- Constant-potential system, 77, 93

- Contracts, 185, 187
 maintenance, 173, 185, 190
 penalties, 174, 193
 specification of equipment, 190, 194
 verification testing, 175, 191
- Contrast, glare due to, 116
 vision by, 108, 110
- Control of light, 56 (see also *Glassware, Reflectors, Refractors*).
 absorption, 56
 diffusion, 57, 61, 63
 diffuse reflection, 57, 60, 63
 refraction, 57, 67
 regular reflection, 55, 57, 64, 67
 of street lighting, 89, 100
 carrier current, 92, 104
 cascade system, 91, 101
 pilot wire, 90, 102
 time switch, 88, 103
- Cost of street lighting, 13, 128, 178
 relative to other items, 11
 of traffic accidents, 14
- Crime reduction, 23
- Current changes, series lamps, 44, 52, 170
 rating of lamps, 44, 45, 53
- Curves, candlepower, 208, 242-264
 isocandle, 214

D

- Daylight, compared with street lighting, 12
 traffic accidents, 21
- Definitions of terms, 202
- Depreciation, equipment, 169, 172
 lamps, 47, 169, 170
- Diffusing glassware, 61 (see also *Glassware*).
- Direct illumination, vision by, 13, 107 (see also *Vision*).
- Direct-current arc lamps, 39, 74
 (see also *Series lighting systems*).
- Distribution, asymmetric, 158, 213
 arc lamps, 31
 isocandle curves, 214
 refractors, 69, 156, 157
 curves, candlepower, 204, 208, 242-264

E

- Equipment, lighting, appearance, 119, 128, 233
 arc, 36, 38
 business district, 129
 depreciation, 169, 172
 fixed charges on, 178
 highway, 156, 157
 location, 17, 111, 115, 157, 161
 mounting (see *Mounting height*).
 obsolescence, 189, 193
 obsolete, 28, 55, 60, 64, 66
 ornamental, 60, 72, 128, 234
 specification of, 190
 thoroughfare, 172
 washing of, 169, 171, 177
- Evaluation of street lighting, 106, 112, 118
- Expenditure for street lighting, 10, 13
 compared with other items, 11

F

- Filament manufacture, 7, 41
- Film cut-out, 82, 131
- Financing of installations, 183
- Fixed charges on equipment, 178
- Flux method of illumination calculation, 221
- Foliage, effect of, 117, 151
- Foot-candle, explanation of, 200, 202
 relation to lumens, 202 (see also *Illumination*).

G

- Gas-filled lamp, theory of, 42
- Gas lighting, 2, 28
 competition with incandescent lamps, 9, 29
- Glare, 55, 113, 232
 background, effect of, 147
 brackets, use of, 116
 diffusing globe, effect of, 116
 glassware, effect of, 116
 highway lighting, 155

- Glare, mounting height, effect of, 113
 street lighting, 55, 113, 119, 232
- Glassware, 61
 cleaning of, 171, 177
 contour, effect of, 63
 glare, effect of, 116
 lanterns, 72, 129
 light control, 70
 ornamental, 129
 prismatic, 67 (see also *Refractors*).
 rippled, 72
 white, 61
- Group transformers, type SL, 83, 86, 87

H

- Highways, accidents on, 155
 legislation for lighting, 235
 lighting of, 155
 night use, 27
 recommendations, 158
- History of street lighting, 1, 55
- Horizontal illumination (see *Illumination*).
- Hours of burning, 169, 176

I

- IL transformers, 53, 82, 83, 87, 131
 individual, 53, 82, 83, 85
- Illuminants, historical, 2, 55
 arc lamps, 3, 30, 35, 188
 Brush arc system, 3, 74
 flaming arc, 34
 gas, 2, 28
 incandescent lamps, 6
 oil lamps, 2, 55
 reverbere, 2, 55
 modern, 28
 gas, Welsbach, 28
 incandescent lamps, 41 (see *Lamps, incandescent*).
 magnetite arc, 37
- Illuminating Engineering Society, 118, 225 (see *Principles of street lighting*).

- Illumination, horizontal, 12
 average, as a standard, 106, 112, 193
 calculation, 217, 221
 glare, subtractive effect, 113, 119
 mounting height, 113
 measurement, 191, 214
 vertical, and silhouette vision, 109
 as a standard, 106
- Installations, financing of, 183
- Insulating transformers, 83, 85, 86
- Iscandle curves, 214

L

- Laboratories, miniature streets, 126
 photometric, 192, 205
 street lighting, 114, 123, 125
- Lamp, magnetic arc, 5, 37
 replacements, cost, 49, 170, 176
- Lamps, incandescent, 41
 competition with gas, 9, 29
 gas-filled, theory of, 42
 life, 48, 50, 52
 manufacture, 7, 41
 minimum size justifiable, 160, 230
 multiple, 43, 45, 95
 characteristics, 47, 52
 rating, 44, 46
 voltage fluctuation, 44
 performance, 47, 51
 precautions in operation, 52
 renewals, 49, 50, 170, 190, 191
 series, 44
 characteristics, 50
 current fluctuation, 44, 52, 170
 rating, 44, 45, 170
 lumen rating, 44, 45, 199
 use on arc lamp circuits, 53, 77
 use on multiple circuits, 54, 99
 use on rectifier circuits, 77
- Lanterns, 72, 129
- Legislation, financing installations, 184
 highway lighting, 235
- Life of lamps, 47, 48, 50, 52
 performance during, 47, 51

Lighting, boulevard, 147
 equipment, brackets, 116, 118,
 145, 151, 161
 brightness, 70
 business district, 18, 124, 128
 gas, 2, 28
 highway, 155
 residence street, 150, 231
 street (see *Street lighting*).
 interior, compared to street
 lighting, 11, 106
 systems, patrolling, 171, 177
 units (see *Equipment, lighting*).
 location, 111, 115, 157, 161
 (see also *Mounting height*).
 in relation to accidents, 17
 planned, zoning in, 121
 Lumen, explanation, 198, 202, 212
 relation to candlepower, 200, 211
 to foot-candles, 202
 Lumens per foot of street, 106, 112,
 124

M

Magnetite-arc lamp, 5, 37
 Maintenance, 168, 185
 contracts, 173, 187, 190, 195
 cost, 146, 181
 importance, 168
 lamp replacements, 49, 170, 176
 patrolling, 170, 171, 177
 washing, 169, 171, 177
 Manufacture, filament, 7, 41
 Measurement of candlepower, 205
 calculation of lumens, 200, 211
 candlepower curves, 208
 isocandle curves, 214
 photometry, 205
 of illumination, 191, 214
 instruments, 215
 Mercury-arc rectifiers, 75, 77
 Miniature streets, 126
 Minimum foot-candles as a stand-
 ard, 112
 Mirrored glass reflectors, 58, 60
 Motorist, viewpoint of, 12, 115, 120,
 145

Mounting height of equipment, 124,
 134, 147, 229
 cost factors, 113, 146
 foliage interference, 117, 118,
 151
 glare, 113, 116
 highway lighting, 157
 maintenance, 145, 151, 154
 recommendations, 124, 132, 148,
 162
 silhouette vision, 109, 111
 trolley-pole standards, 134, 136
 Multiple lamps (see *Lamps,*
incandescent).
 lighting systems, 95, 99
 control, 100 (see also *Control*).
 in large cities, 96
 underground cable, 99
 vs. series systems, 96
 with series lamps, 54, 99

N

Nomenclature, 202

O

Oil lamps, 2, 55
 Operating costs, 178

P

Patrolling of lighting systems, 171,
 177
 Pavement brightness, 106, 108, 111
 character, 108, 111, 159, 227
 Pedestrian, lighting for, 119
 Penalties for outages, 174, 193
 Performance of lamps, 47, 51
 Photometry, 205
 Pilot-wire control, 90, 102
 Planning (see *Street lighting*).
 Point-by-point method, 217
 Posts, ornamental, 123, 134
 trolley-pole combination, 134
 Power factor, lamps, 44
 series lighting equipment, 75, 83
 Principles of street lighting, IES, 225
 appearance, 233
 condition of street, 227

- Principles of street lighting, glare, 232
visibility, 228
- Prismatic glassware, 67 (see also *Refractors*).
- R
- Reactance regulators, 78, 93
- Recommendations, lighting, 124, 131
boulevards, 147
business districts, 124, 131
highways, 124, 158
residence streets, 124, 152
thoroughfares, 124, 148
- Rectifiers, mercury arc, 75, 77
- Reflection, control of light, 55, 57, 63, 67
specular, 55, 57, 67
- Reflectors, diffusing, 60, 63, 65
mirrored glass, 58, 60
polished metal, 2, 55, 57
porcelain enamel, 63
specular surface, 55, 57
- Refraction, control of light, 57
- Refractors, 69, 156, 157
asymmetric distribution, 158, 213
light distribution, 69, 151
"white-way" lighting, 72, 129
- Renewals of lamps, 49, 50, 170, 190, 191
- Requirements of street lighting, 10
- Residence street lighting, 150, 231
multiple distribution, 97
recommendations, 124, 152
- Reverberate, 2, 55
- Rippled glassware, 72 (see also *Glassware*).
- S
- Series lamps, 44 (see also *Lamps, incandescent*).
lighting systems, 74
alternating-current supply, 77
constant-current transformers, 77, 78, 88
constant-potential transformers, 77, 93
group transformers, 83, 86, 87
- Series lighting systems, alternating-current supply,
reactance regulators, 78, 93
connection of lamps, 44, 53, 82, 83, 86
control, 89
cost of operation, 178
direct-current supply, 74
Brush generator, 75
mercury-arc rectifier, 75, 77
- Shadows, vision by, 111
concealing, 117, 119, 151
Silhouette vision, 108, 110
- SL group transformers, 83, 86, 87
- Specifications, equipment, 190, 194 (see also *Contracts*).
lamp performance, 189
maintenance, 173
- Specular reflection, 55, 57, 67
vision by, 112
- Straight series operation, 83, 131
- Street lighting, appraisal, 106, 112, 118, 225
benefits, 14
accident prevention, 14
comfort and convenience, 26
commercial, 14, 26
crime reduction, 23
compared with daylight, 12
with interior lighting, 11, 106
control, 89, 101
cost, 11, 128, 178
expenditures, 11
financing, 183
glare, 55, 113, 119, 232
history, 1, 55
incandescent lamps, 44, 45, 95
laboratories, 114, 123
in miniature, 126
planning, 121
(see also *Recommendations, lighting*).
business districts, 18, 124, 128
residence streets, 124, 150
thoroughfares, 124, 145
white-way, 124, 130
zoning, 121
- principles, 10, 225
requirements, 10

Street lighting, purposes of, 10, 13, 225
 series lamps (see *Lamps, incandescent*).
 System, constant potential, 77, 93
 multiple, 95, 99
 series lighting, 74

T

Terms, explanation of, 196, 202
 Tests, candlepower, 192, 205
 equipment, 191
 illumination, 189
 lamps, 48, 168
 verification, 191
 Thomson-Houston arc system, 3
 Thoroughfare lighting, 145, 231
 recommendations, 124, 148
 Time switch control, 88, 103
 Traffic density, 10, 26, 145, 155 (see also *Accidents*).
 Transformers, auto, 82, 83, 85
 constant-current, 77, 78, 88, 180
 constant-potential, 77, 93
 IL individual, 53, 82, 83, 85
 insulating, 83, 85, 86
 reactance regulator, 78, 93
 RO constant-current, 77, 78, 88, 180
 SL group, 83, 86, 87
 two-coil insulating, 83, 85, 86
 Tungsten filaments, 7, 41, 43
 characteristics, 7, 44, 47

U

Units, lighting (see *Equipment, lighting*).
 Underground cable, 99, 164

V

Vertical illumination, 106, 109, 119
 Visibility, factors affecting, 106, 228
 direction of light, 109
 glare, 113
 pavement surface, 108
 Vision, 12
 color of object, 107
 direct illumination, 107
 pavement brightness, 106, 108, 111, 146
 shadow, 111
 silhouette, 108
 specular reflection, 112
 Voltage fluctuations, multiple lamps, 47, 48

W

"White-way" lighting, 10, 13, 26, 130 (see also *Business-district lighting*).
 Washing of lighting equipment, 169, 171, 177

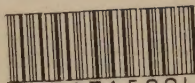
Z

Zoning in planned lighting, 121

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